THE HUMAN SPINE IN HEALTH AND DISEASE

ANATOMICOPATHOLOGIC STUDIES

BY

GEORG SCHMORL († 1932), M. D.

CLINICORADIOLOGIC ASPECTS

BY

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THE FIRST AMERICAN EDITION, TRANSLATED AND EDITED BY

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1959

GRUNE & STRATTON NEW YORK AND LONDON

TRANSLATED FROM

DIE GESUNDE UND DIE KRANKE WIRBELSÄULE

IN RÖNTGENBILD UND KLINIK

BY

GEORG SCHMORL† AND HERBERT JUNGHANNS

VIERTE, ERWEITERTE AUFLAGE

PUBLISHED BY THE GEORG THIEME VERLAG

STUTTGART, 1957

Preface to the First American Edition

It is unfortunate that the wealth of scientific knowledge contained in the classic monograph of Schmorl and Junghanns has not, heretofore, been available to English-speaking students. Their meticulous observations and the vast amount of material studied makes this work a most authoritative treatise on the anatomy, the physiology and the pathology of the human spine.

In the Dresden Institute of Pathology, Schmorl removed ten thousand spines at autopsy. These were studied as gross specimens *in toto*, and by sectioning. Radiographic studies were supplemented by microscopic sections and careful attention was paid to such minute details as the histology of the vertebral body-disc junction, the water content of the nucleus pulposus and the relation of degenerative changes in the annulus fibrosus to the prolapse of fragments of disc tissue.

One may well reflect that, before such studies had been made, our knowledge of the variations in the anatomy and the physiology of the spine, and of the various traumatic and pathologic changes which may involve it, was determined largely by the co-ordination of objective and subjective clinical findings with radiographic observations. On this basis rested a considerable body of knowledge which was greatly augmented and even altered quite markedly by the enormous amount of completely objective evidence presented by Schmorl and by Junghanns.

It is the hope of the editors that this first American edition of *The Human Spine in Health and Disease* will be received by the medical profession of the English-speaking world with the enthusiasm which greeted the appearance of the German text.

This monograph first appeared in 1932 as the work of Prof. Dr. Georg Schmorl and Prof. Dr. Herbert Junghanns, and at once became the authoritative work on the spine. It was followed in rapid succession by three German editions under the direction of Professor Junghanns after the death of Professor Schmorl, and has been published in one French edition.

In attempting this translation we have encountered certain difficulties which, no doubt, are common to all attempts to render faithfully, in any given language, the thoughts expressed in another. To this end we have omitted, occasionally, a sentence which seemed irrelevant, and we have taken certain liberties with the terminology employed. Such changes have been noted in "editorial notes," whenever they have occurred for the first time, and we wish to call attention here to some of them. The word "apophysis" has a different meaning in the German text than that assigned to it in our literature, and hence, we have employed the term "small vertebral joints," rather than "apophyseal joints" to describe the articulations of the vertebral articular processes. "Vertebral plate," "vertebral rim" and "cartilaginous plate" are unfamiliar terms, the meaning of which is made quite clear in the text, and "retrolisthesis" is a descriptive term unknown in English.

We realize that the reading of this monograph is made somewhat difficult by the inclusion in the text of a large number of writers who are cited as references. In the British and American literature we are accustomed to seeing such references indicated as subscripts directing the readers attention to a bibliography which follows a chapter or a book. Since there are nearly three thousand citations, the use of subscripts seems rather impractical and we have left the names of the various authors in the text as in the German edition.

We wish to thank Dr. Frida Bier for putting at our disposal a few sections of her version of the translation. We express to Wanda Wilk our deep appreciation of her wholehearted and enthusiastic help and co-operation, without which the task of preparation of this edition could not have been completed.

Los Angeles, February, 1959

Stefan P. Wilk, M. D.

Lowell S. Goin, M. D.

Preface to the First German Edition

This monograph is a resume of my investigations of the anatomy, the pathology and the radiology of the spine. These investigations will, it is hoped, lead to a better understanding of the various pathologic processes which may involve the spine and, with comparison between anatomic specimens and radiographic material, form a solid basis for accurate clinicoradiologic diagnosis.

Continued progress in the technics of radiography has enabled us to produce superior radiographs and to demonstrate details of spine structure scarcely possible until fairly recent years. If radiologic diagnosis is still beset by difficulties, it is due, in part, to the peculiarities of the anatomy of the spine and, in part, to lack of exact knowledge of the pathologic processes which must be recognized.

The pathologic anatomy of various organs and systems is based, essentially, on systematic post-mortem examination. The spine, however, has not heretofore been subjected to such a systematic study and, in general, has been investigated only when ante-mortem findings suggested the need of such study and, usually, only in the region of the presumed lesion.

In 1925, in our Institute, we began the regular and systematic post-mortem examination of the spine, and the study of its anatomic and pathologic modifications. At every autopsy the spine was inspected first *in situ*, and was then removed and subjected to a careful and detailed study of its various components. The number of spines thus examined exceeds ten thousand, and this large amount of material forms a sound basis for our observations.

These studies offered an opportunity to observe lesions frequently ignored or poorly understood, and frequently to follow their evolution. Moreover, we became conscious of the limitations of our anatomic knowledge of the normal spine and especially of its development during the growth period. Many details which were of great significance in the ultimate development of the spine were not even mentioned in the standard textbooks of anatomy.

It would be futile to attempt any detailed technical description of the methods employed in our investigations. It will suffice to say that the choice of the method employed was determined by the special features of the case under consideration, the modifications encountered in the preliminary examination of the spine, and the component elements which demanded particular study. The intervertebral disc, for example, (of such great importance for spine function) must be examined as a fresh specimen, while the bony elements are better studied in a dry specimen.

In the course of our studies radiography rendered us a great service. Although this method permits an examination of the bony structures which is, perhaps, somewhat less exact than the examination of a macerated specimen, it has certain distinct advantages. It does not involve the destruction of soft tissues which we were anxious to preserve for subsequent histologic study, and it permits the visualization of the interior of a bony structure where one might discover lesions which escaped detection in a macerated specimen.

The use of radiography was not motivated entirely, however, by anatomic and pathologic considerations, but by my desire to make the clinician and, especially, the radiologist, the beneficiary of my observations and, to this end, we prepared a certain number of radiographs of specimens with quite obvious anatomic and pathologic changes.

I regret that it was not always possible to correlate my anatomic and pathologic findings with clinical data. This is because the spine is less accessible for clinical exploration than are the viscera and, moreover, is ordinarily examined, radiographically, when there is some clinical evidence of trauma or disease. Hence, it was not always possible to offer an anatomicopathologic interpretation of the radiographic findings.

We did not follow Böhmig's practice of radiography of cadaver material, since we felt that it offered no material advantage.

Very commonly we used radiography to study spines which had been removed at autopsy and frequently after sagittal section of such spines Radiographs produced thus nearly always display features somewhat different from those seen by clinical radiography Definition and detail are better, because of the absence of the shadows of numerous superimposed structures, including the soft tissues Although the comparison of such radiographs and those of living subjects is difficult, they are extremely useful because they offer reference points of great value when attempting the interpretation of the less well-defined shadows to which we are accustomed in clinical radiography They serve, too, to establish the limits beyond which we can scarcely hope to pass in everyday radiologic examination Confronted with an anatomic specimen, and a radiograph of it, the radiologist is better prepared to grasp the nature of the pathologic process and, thus, constantly augments our knowledge of the anatomy and the pathology of the spine Hence, diagnostic radiology acquires a firm foundation of anatomy and pathology, and this has been the intent of this monograph

Some of the results of my research have been published, previously, by me and my associates Some, with especial radiologic interest, have appeared in the *Fortschritten auf dem Gebiet der Röntgenstrahlen* Professor Grashey, the editor of this journal, recognized the value of the radiologic aspects of my work, and urged me to publish my studies as a monograph This, after some hesitation, I decided to do

Since, in my capacity of anatomist and pathologist, I was not overly acquainted with the specialty of radiology and had not familiarized myself with its literature, I thought it essential, for the production of a work destined for radiologists and practitioners interested in clinical radiology, to secure the collaboration of my colleague Dr Herbert Junghanns Dr Junghanns, who is a most competent radiologist, and thoroughly familiar with the entire field of radiology has long been a valued associate in the Dresden Institute of Pathology His active participation in my investigations has made him completely familiar with them and with the fundamental ideas which guided them

The preparation of the anatomic specimens and the photography of them was carried out by me, personally The radiographs were made in the Department of Radiology of the Friedrichstädt Hospital and I acknowledge my indebtedness to its director, Professor Arnsperger, who kindly permitted me to use his department Finally, I wish to express my heartfelt thanks and appreciation to the publisher, the Georg Thieme Verlag, and its director, Dr Hauff, for the publication of so handsome a monograph in these times of grave economic crisis

Dresden, March, 1932 *Georg Schmorl, M D*

Contents

I. The Development and the Normal Structure of the Spine

Physicians who interest themselves in the diagnosis and treatment of diseases and injuries of the spine will profit greatly by a clear understanding of its anatomy and the developmental stages through which it passes. As the first step toward this understanding, we shall discuss briefly the more important anatomic aspects, the development of the spine and, in somewhat greater detail, certain developmental variations and pathologic changes not always demonstrable radiographically. We have found that many modern textbooks of anatomy or pathology may omit details which we consider to be of considerable importance. Not only are there omissions, but various false concepts of the nature of certain disease, and the changes which may occur in trauma and disease have been perpetuated by uncritical transference from one text to the next. This is true in reference to the developmental processes of the body-disc series, a matter of great importance in the study of most diseases of the spine. This will be discussed in some detail later.

Most textbooks give rather complete information as to the interrelationships of the individual components of the spine and the radiographic findings seen in the various projections in common use (Grashey, Köhler, Liechti, Schinz, Simons et al.). These texts usually discuss the various shapes of the vertebral bodies and their processes, and the relationships of the bodies and processes to each other. Usually, the authors describe the technics (including usual angles of projection necessary for a proper radiographic study of the spine), and these details we assume to be known to the reader.

The comparative anatomy of the multiple components of the vertebral column and the embryology of the spine form a sound basis for the recognition and understanding of the various anomalies which may occur. These will be considered in the discussion of the specific malformations of the spine and its components (see Chapter II), and since a too detailed discussion of the prechondral and cartilaginous phases of spinal development would lead us too far from the more practical aspects, we shall begin with a description of the ossification process, the process which makes the spine recognizable in a radiograph. The earlier developmental phases will be mentioned briefly wherever it seems desirable, but the reader who wishes more detailed information will find it in various textbooks by Bardeen, Braus, Broman, Rabl et al.

A. The vertebral bodies

The first radiographically demonstrable ossification of the vertebral bodies occurs in the third month of embryonic life. It occurs first in the lower thoracic and upper lumbar vertebrae (Alexander, Böhmig, Broman, Hartmann, Jonata, Nuvoli, Schaffer, Schinz and Töndury, Tata et al.), and proceeds rather rapidly cephalad and somewhat more slowly caudad. By the end of the fourth month ossification centers will have appeared in all of the vertebral bodies. (Ossification of the vertebral arches follows a somewhat different pattern, which will be described later.) In the newborn infant the ossification center of a vertebral body is ovoid (as may be seen in a lateral radiographic projection), and its vertical diameter is about that of the disc space (fig. 1). It exhibits anterior and posterior indentations, and linear radiolucencies pass horizontally across its center. Both the indentations and the linear radiolucencies are produced by the vascular channels passing horizontally through the ossification centers. The ossification center of each vertebral body is separated from that of the vertebral arch by a fairly broad linear radiolucency (the so-called "vertebral arch epiphysis"), representing the "intervening cartilage" (figs. 1, 4, 5 and 6). At this stage of the development of the spine, the abundance of the chondral elements may be estimated by the height of the disc spaces.

Fig 1 (left) Lateral radiograph of the spine of a newborn girl Ovoid vertebral bodies High biconcave intervertebral discs The intervening cartilages (between the neural arches and the vertebral bodies) are recognizable as broad spaces The linear radiolucencies running horizontally through the vertebral bodies represent the vascular channels

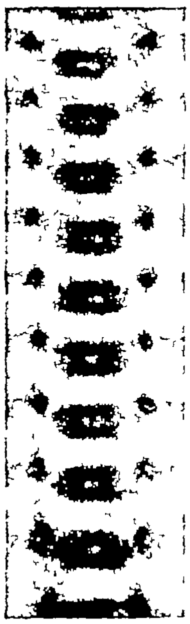


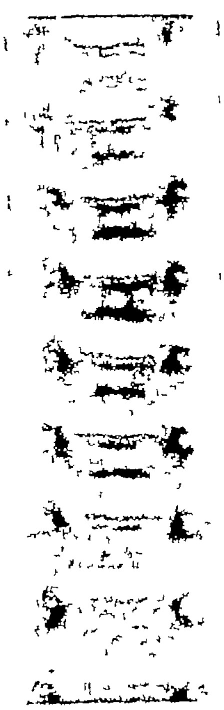
Fig 2 (right) Anteroposterior view of the specimen shown in figure 1 The height of the discs is relatively great compared to the height of the vertebral bodies The vascular channels appear as small linear radiolucencies, some of them doubled, in the centers of the vertebral bodies

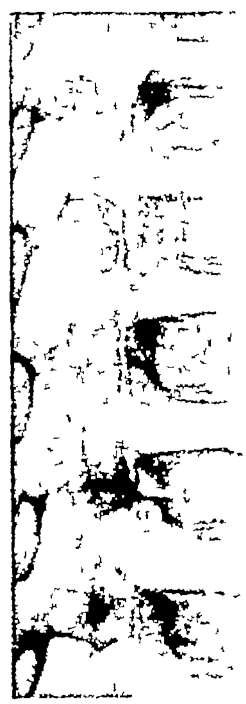
As development progresses, the vertebral bodies (as seen in a lateral radiograph) begin to assume rectangular forms The linear radiolucency produced by the vascular channel persists, and the anterior margin of the vertebral body remains slightly indented. There is, however, a very noticeable increase in the height of the vertebral bodies, as compared to that of the disc spaces (fig 4)

In the newborn infant the ossification center of a vertebral body (as seen in the anteroposterior radiograph) appears as a broad oval (fig 2) Occasionally, the upper and lower surfaces of this oval are slightly indented, producing a shadow resembling that of the figure 8 placed horizontally (fig 3) The shape of the ossification center (as seen in a lateral radiograph) gradually approaches the rectangular

In infants the vascular channels are recognizable in both the lateral and anteroposterior projections as small radiolucent areas in the vertebral body (figs 1—3) As the infant grows, the vascular channels usually disappear in the anteroposterior projection, but remain visible in the lateral projection until, with the completion of growth, they are overshadowed by the condensing spongiosa, in the adult they are only rarely recognizable When they are recognizable, they may be seen (in the lateral radiograph) in one or several of the vertebrae (Hahn, Hansen, Meyer and Sichel et al) Ignorance of this developmental variation may lead to the erroneous diagnosis of fracture Zolotuchin, by injection of the vertebrae in fresh cadavers, studied the blood supply to the vertebrae and found from fifteen to eighteen nutrient arteries with numerous anastomoses to be present in each vertebral body Wagoner and Pendergrass have also written on this subject

As the size of the vertebral body increases, there are seen in a lateral projection step-like recesses in the anterior margins of the vertebral bodies, and these have about the same density as that of the disc space (figs 7 and 8) At times, they may be seen in the lateral margins in an anteroposterior radiograph, and here the





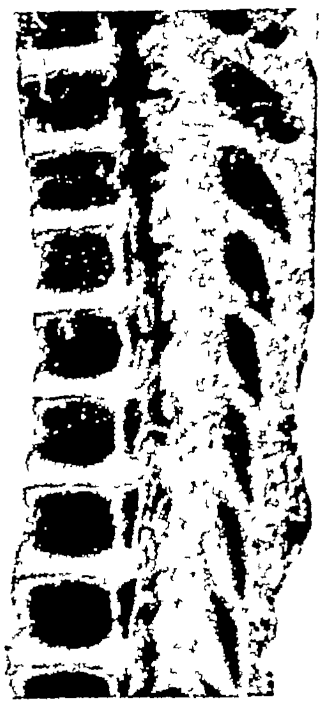


Fig 3 (left) Anteroposterior radiograph of the spine of an infant aged 3 weeks Slight central depressions in the vertebral bodies

Fig 4 (center) Lateral radiograph of the spine of a boy, aged 4 The disc spaces have become less than the height of the vertebral bodies. The vertebral bodies have assumed more nearly rectangular shapes; the cartilage between the vertebral body and the neural arch is recognizable as a narrow fissure

Fig 5 (right) Photograph of a sagittal section of the spine Child, age 3 Intervening cartilages between the vertebral bodies and the arches are clearly recognizable

recesses seem to be somewhat more shallow These findings represent the "cartilaginous rim," an annular recess surrounding the margins of the vertebral body, and deeper anteriorly than laterally or posteriorly This "cartilaginous rim," which persists until about the seventh year of life, will be described later in more detail

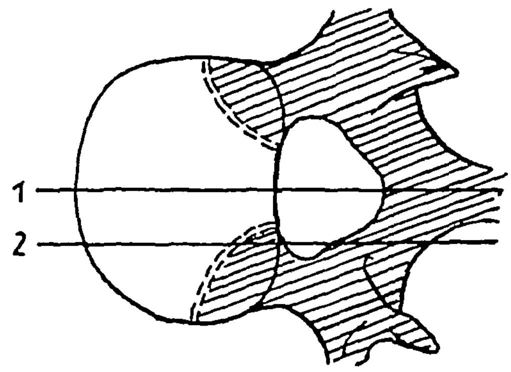
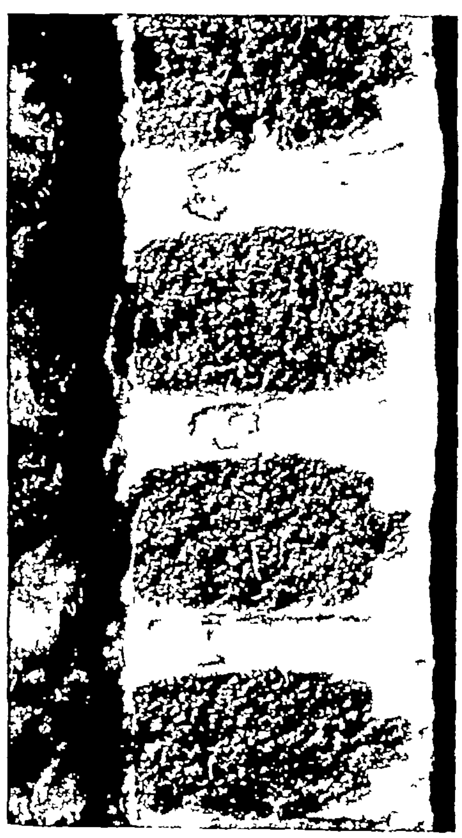


Fig 6 Diagram of a vertebra seen from above The cross-hatching represents the ossification centers of the vertebral arch, which also contributes to the formation of the posterolateral portions of the vertebral body The intervening cartilage between the neural arch and the vertebral body (the so-called "vertebral arch epiphysis") lies between the curved broken lines Line 1 passes through the sagittal plane, while line 2 represents a parasagittal plane corresponding to the section of the vertebral body which is shown in the lower portion of figure 5 A section in this plane, therefore, crosses the ossification centers of the vertebral body and of the arch, as well as the intervening cartilage

If one examines a macerated vertebral body at this stage of development (after dissecting it from the spine), a peculiar appearance will be noticed (fig 10) Its upper and lower surfaces will be seen to consist of thin, rough bone (best termed "the vertebral plates") in which fine cribriform-perforations are distinctly recognizable A zone of somewhat greater density and with fewer perforations will be seen on the border of each surface between the central and posterior thirds The nucleus pulposus is located on this strengthened area which, thus, may be properly called a "stress-bearing zone "

The surface of each vertebral body exhibits, near its edges and especially near its anterior edge, radial irregularities extending peripherally and producing a dentate appearance (fig 9) These slight irregularities, with flattened grooves between them, extend inward from 7 to 11 mm , with gradual decrease in their breadth and height Some of these irregularities may be found on the posterior aspect of the vertebral body They are short (from 3 to 7 mm in length) and the number of grooves varies within broad limits On the anterior surface of the vertebral body, there will be seen, at least, two (as on the sacral segments) or as many as seventeen grooves (twelfth thoracic vertebra) The superior vertebral body surfaces will show as few as four grooves (on the sacral vertebrae) and as many as sixteen grooves (on the twelfth thoracic segment) These grooves are, invariably, deeper anteriorly and somewhat more shallow laterally They are most conspicuous between the midthoracic and the midlumbar sections of the spine and are rather less well defined in the cervical and upper thoracic areas This grooving, although recognizable in



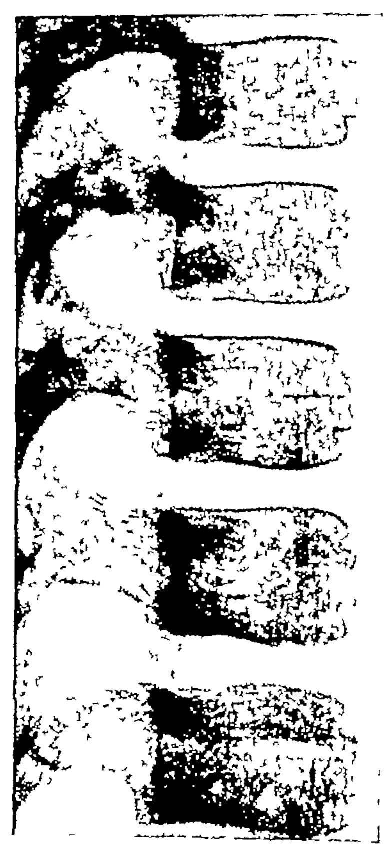


Fig 7 (left) Sagittal section of the spine Boy, age 7 The cartilaginous rims are seen as step-like recesses on the anterior contours of the vertebral bodies Somewhat similar areas also appear on the posterior surfaces

Fig 8 (right) Lateral radiograph of a sagittal section of the spine Girl, age 7 The intervertebral spaces are narrower as compared with the vertebral bodies Step-like recesses are seen in the vertebral bodies, above and below, and the cartilaginous "vertebral body rims" lie in these recesses The vertebral bodies and the arches have united and the intervening cartilage cannot be seen

Fig 9

Fig 10

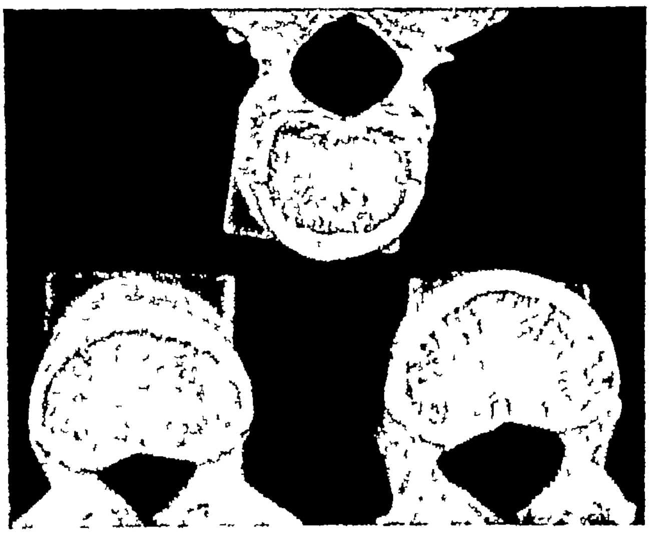


Fig 11

Fig 9 (above) Anteroposterior view of a macerated spine Girl, age 6 The grooving of the vertebral body edges extending for a few millimeters on the body walls of the vertebra can be easily seen The cartilaginous rims lying in the step-like recesses of the grooved edges of the vertebral bodies have been destroyed by the maceration The perforations in the exterior surfaces of the vertebral bodies are vascular channels

Fig 10 (center) Photograph of the superior surface of a macerated vertebral body seen from above Boy, age 10 The vertebral body surface shows fine perforations along the periphery (they are somewhat closer together in the center) Grooving along the vertebral body edges can be seen distinctly The ridges and furrows of this grooving extend for some millimeters towards the center of the vertebral body surface The slight arcuate depression near the pedicle marks the position of the intervening cartilage ("arch epiphysis", cf figs 6 and 61)

Fig 11 (below) Photograph of the vertebral plate surfaces of three vertebral bodies Male, age 17 The bony rims appear as closed rings on the edges of the vertebral plates They are somewhat broader anteriorly than laterally and posteriorly The outer portions of the vertebral body surfaces still show some indication of the radial grooving, disappearing beneath the superimposed bony rims

the vertebrae of the newborn infant, becomes more distinct after the age of six, and is most pronounced between the ages 8 to 10 The grooves persist after the bony rims (to be discussed in detail later) have formed, and aid in the proper interlocking of the segments Since the grooves extend toward the center of the vertebral plate and beyond the bony rim, they remain visible after the formation of the rim (fig 11) Only after growth is complete (from the twenty-first to the twenty-fifth year) does obliteration of the grooves occur, and the upper and lower surfaces of the adult vertebral body (fig 20) have an appearance quite different from that of the juvenile vertebra (fig 10) It is particularly remarkable that the perforations of the superior and inferior vertebral body plates are much larger in the adult than in the young

On inspection of a macerated juvenile vertebral body (fig 9), one may recognize the fine grooving just described, and the manner in which it extends over the annular recess on the edge of the body This may be seen quite well in a lateral radiograph (fig 8), and one notes that the grooved appearance is most marked on the superior and the inferior thirds of the anterior surface of the vertebral body Close inspection of the macerated vertebral body demonstrates that a cortical layer of compact bone (as is commonly seen in the long bones) does not exist in the vertebral body The anterior surface is porous and has many openings for vascular channels, frequently arranged in regular pattern following the curvature of the upper and lower vertebral margin. These anatomic details are not of great practical significance Parenthetically, we will observe that the shape of the vertebral body of the juvenile, deviating as it does from that of the adult, is important in judging the age of the subjects, and thus may be of significance in forensic medicine (Merkel)

The cartilaginous plate (a layer of flat-cell hyaline cartilage) lies on the surface of the vertebral body between the disc and the vertebral plates firmly united with the disc This cartilaginous layer fits the body as an overhanging lid fits a jampot, and fits closely into the recess in the vertebral body edge on the anterior, lateral and posterior aspects of the vertebral body It is closely enmeshed with the ledges and grooves of the vertebral body, as we have described, and thus furthers union, surface enlargement and better nutrition The growth of the vertebral body in its vertical diameter proceeds from the cartilaginous layer, and one can demonstrate, microscopically, the columnar or palisade arrangement of the cartilaginous cells, which resembles that seen in the growth areas of long bones

Fig 12 Anteroposterior view of a section of the macerated spine Man, age 23 The bony vertebral body rims are demarcated from the vertebral body by fine curved lines

The "rim-shaped" process, appearing as an extension of the cartilaginous layer into the annular recess of the body edge, and which may be termed "cartilaginous rim," is seen, in the sagittal section, as a small area of cartilage cutting into the body edge (fig 7) A step-like recess is recognizable in the radiograph at this stage of development (fig 8) Small calcium foci appear in the cartilaginous rim at the age of 6 to 8 in girls and 7 to 9 in boys Gradually, these calcified foci ossify by vascular infiltration (Schmorl) At this age they can be demonstrated in good lateral radiographs of a living subject In the textbooks the appearance of the ossification centers of the rims is commonly attributed, incorrectly, to a later age Harrenstein reports that, in the literature, the age is given as varying from 11 to 21 years The first foci of calcification are observed in the grooves which have been mentioned, and which have been

Fig 13

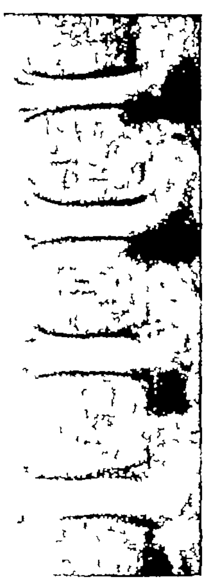


Fig 14

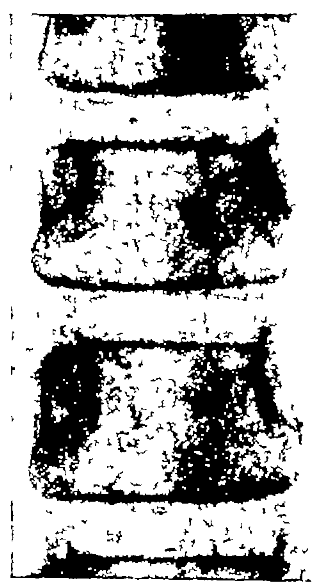


Fig 15

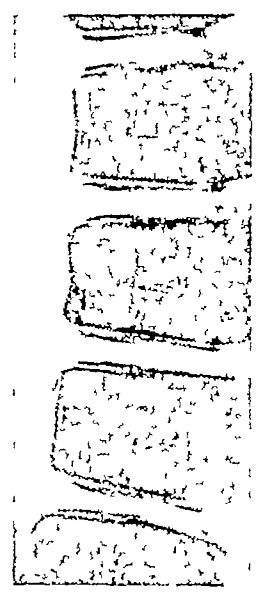


Fig 16

Fig 13 Photograph of the left half of a sagittal section of the spine Boy, age 16 Small triangular sections of the rims (the "vertebral body epiphyses") are seen on the anterior vertebral body edges, separated from the vertebral bodies by a cartilaginous zone

Fig 14 Lateral radiograph of the spine Girl, age 10 The "anlage" of the bony rim lies in the step-like recess on the anterior vertebral body margins There are also shallow posterior recesses corresponding to the posterior portion of the ring-like cartilaginous rim, changing gradually into the bony rim ("vertebral body epiphysis")

Fig 15 Anteroposterior view of part of the spine Girl, age 8 The interrupted, thin linear outline of the vertebral body rim, in its early phase of ossification, is superimposed on the upper and lower vertebral body edges

Fig 16 Radiograph of a sagittal section of the spine Boy, age 9 The thin lines, partly broken and paralleling the upper and lower vertebral body margins, are the projections of the ring-shaped rims in their early phase of ossification

described in detail by Schmorl Gradually, the foci of ossification, dispersed within the rim, unite and form the "bony vertebral rim," initially separated from the vertebral body by a cartilaginous layer (figs 11—21, diagram in fig 22) Fusion of the individual foci of ossification to form the annular rim is completed at about 12 years, but the completion of the process of ossification is not simultaneous in all vertebrae Thus, it is possible that in the same vertebral body, the superior rim may be completely ossified while the inferior margin remains cartilaginous, and vice versa When these irregular rim ossifications are observed in a radiograph, one should not, without other evidence, infer that abnormal development has occurred Lindemann's case of a mentally defective girl, about 6 years old, with congenital lues and with completely developed rims is an unusual one The breadth of the bony rim varies greatly in the different regions of the spine, and exact measurements and average values may be found in Niedner's work

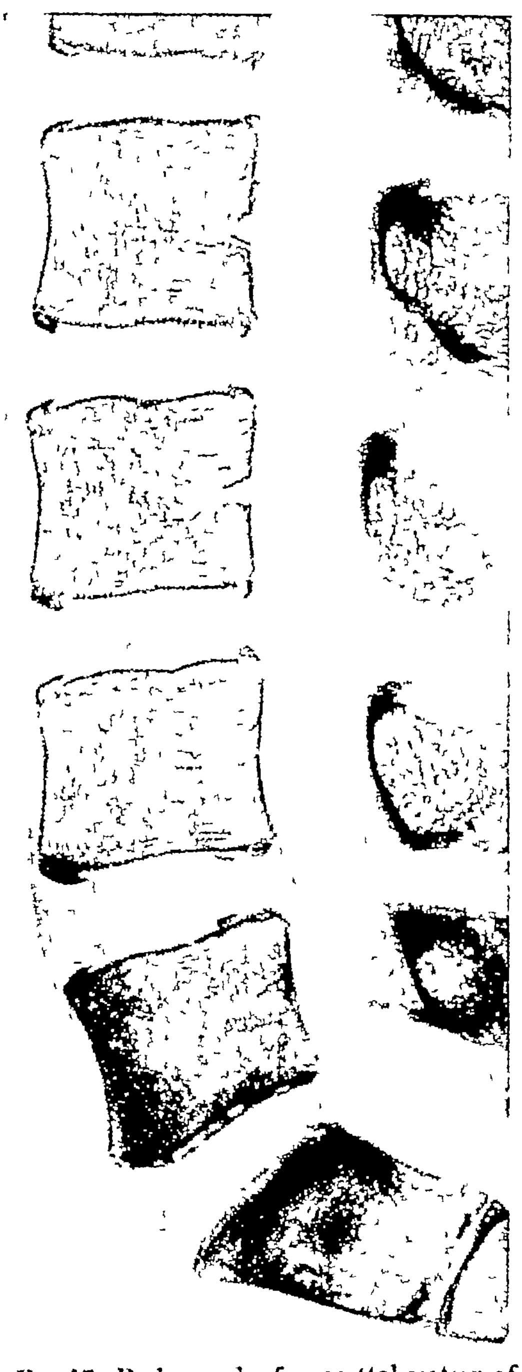


Fig 17 Radiograph of a sagittal section of the spine Girl, age 15 Beginning fusion of the bony rims and the vertebral bodies In the lower part the section has deviated somewhat from the sagittal plane and the lateral portions of the rims are superimposed on the vertebral body surfaces as small bone fragments

At this stage of development (about age 12) a lateral radiograph will show small bone islets (fig 14) with a fine posterior process representing the projection of the annular bony rim on the anterosuperior and the inferior body edges Radiographically, these bone islets have been considered erroneously, as tuberculous sequestra (Lehrnbecher), but this has been disproven by Harrenstein A lateral radiograph of the spine will show the bony rims as fine lines paralleling the upper and lower vertebral body surfaces (fig 16) In figure 16 the plane of the section is too far laterally for the step-like recesses to be demonstrated

The union of the vertebral rim and the vertebral body does not occur simultaneously in all of the vertebrae and takes place last in the lumbar segments Figure 17 shows union to have occurred in some of the vertebrae, while others remain separate, appearing as somewhat triangular sections of the rim Since, in the lower part of figure 17, the section deviates somewhat from the midline one will notice features which resemble those seen in figure 16 Small triangular portions of the vertebral rim may be seen on the third and fourth lumbar vertebrae, on the second sacral segment and on the posterior edges of their bodies as well In an anteroposterior radiograph, made at this stage of development, the union of the marginal bony rims and the vertebral bodies is seen as a linear density closely paralleling the body surface (fig 18) Similar appearances may be noted in lateral radiographs of any spine in a similar stage of development (fig 19)

A macerated specimen (fig 12) seen in the anteroposterior projection, will show that the step-like recesses of the infantile vertebra have been filled by a bony ring, easily seen on inspection of the upper and lower surfaces of the vertebra (fig 11). One may recognize the vertebral rim as a ring, superimposed on the porous vertebral plate of the vertebral body somewhat broader anteriorly than posteriorly or laterally, but surrounding the vertebral body as a completely closed ring of dense bone The cartilaginous plate, which was destroyed by the process of maceration, (figs 11 and 20) is superimposed on the perforated vertebral plate within the circumference of the vertebral rim

With the x-ray beam directed obliquely and with the vertebral body surfaces seen as flat ellipses, the vertebral rim may be quite clearly visualized In figure 21 the upper and lower surfaces of the vertebral bodies are seen as ellipses on which, about 1 cm behind the vertebral margins, arcuate densities may be seen, and these represent the posterior borders of the bony rims, which are completely fused with the bodies and which enter the "perforated" vertebral plates in step-like fashion Careful inspection of a radiographic film of the spine of a living person will demonstrate similar findings (Steiner, Runge) One must note carefully that these findings will be observed also in the adjacent vertebrae, and thus one will avoid mistaking these normal features for pathologic variations

We have discussed the formation and the radiographic features of the annular vertebral rim (fig 22) in considerable detail, because a thorough comprehension of the embryology and anatomy of this portion of the vertebra is essential to the understanding of the pathologic processes which involve the border of the intervertebral disc and the vertebral body Heretofore, the term "vertebral body epiphysis" has been widely used to indicate the vertebral rim, but Schmorl has demonstrated that it is an error to compare this so-called "epiphysis" to that of a long bone, since it contains no growth layer facing the disc and is not, in fact, an "epiphysis" (cf Böhmig,

Fig 18

Fig 19

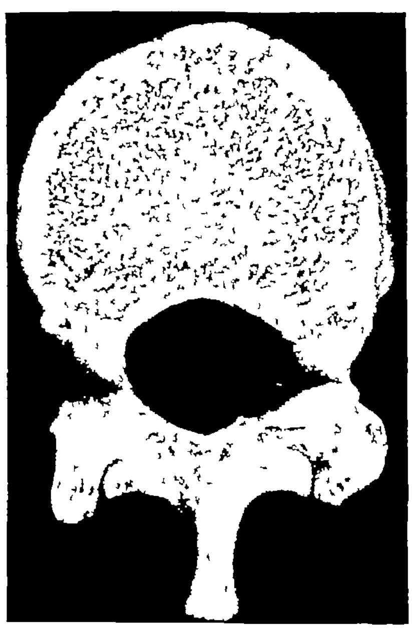


Fig 20

Fig 21

Fig 18 Anteroposterior view of the thoracic spine Girl, age 15 The ring-shaped rims are seen as narrow band-like shadows superimposed on the superior and inferior vertebral margins

Fig 19 Radiograph of a sagittal section of the spine Girl, age 17 The fully developed rims considerably reduce the width of the disc spaces The spongiosa of the vertebral bodies is merging gradually into the bony rims on the anterior body margins, and bony union between the rim and the body is occurring

Fig 20 Photograph of the superior surface of a macerated vertebra of an adult The center of the vertebral plate is fairly dense, although slightly porous Numerous large perforations lying close together extend toward the periphery The bony rim forms a narrow and compact ring of bone The grooving which is generally seen on the juvenile vertebral bodies (see figs 10 and 11) has disappeared

Fig 21 Lateral radiograph (with slight deviation from the lateral) of the thoracic spine Woman, age 28 The projection causes the upper and lower surfaces of the vertebrae to appear elliptical About 1 cm behind the anterior vertebral margins, arcuate shadows represent the inner borders of the bony rims In this region the bony rim descends, step-like, into the vertebral plate

Luschka) Although the vertebral rim might be considered, from the standpoint of embryologic development, as a "rudimentary vertebral body epiphysis" it will be better, for the understanding of the anatomic structure and its relation to radiographic findings, to avoid the term, and to use, instead, "vertebral body rim" or "vertebral rim" This term has the further advantage of constantly reminding one of the annular character of the rim We hold this opinion despite the fact that, in the literature there are constant references to the "epiphyseal discs," "epiphyseal plates," and to the "disc-shaped epiphyses of the vertebral bodies" (Köhler, Ruckensteiner, Janker et al) Braus for example, says that the vertebral body epiphyses ossify from the twelfth year onward as "flat bone discs," and Hasselwander, in his monograph on the juvenile bony skeleton, illustrates what he calls a "disc-shaped vertebral body epiphysis" This may lead to grave errors since those using these designations are apt to describe as "epiphyseal disease" disturbances occurring in the center of the disc-vertebral border, a designation which does not, in our opinion, correspond to the facts All mammals, except the anthropoid apes have disc-shaped "epiphyses" on the surfaces of the vertebral bodies, but these do not show growth zones facing the discs In autopsies performed on two orangutans and on one gorilla, we found ring-shaped "epiphyses" which were considerably broader than those found in humans Beadle of Schmorl's Institute has presented the results of the investigations of animal vertebral epiphyses, and it is hoped that they will stimulate further investigations in this field, since exact knowledge may well explain many problems of the anatomy and pathology of these structures in human beings

Galeazzi regards the vertebral rims and the cartilaginous plates as epiphyses because he found cartilage on the side of the rim facing the disc, but this statement requires careful analysis from the standpoint of the anatomist Runge, in a detailed discussion of the question of secondary ossification centers in the vertebral body, refers to the literature and to his own radiographic material and reaches the conclusion that the vertebral rim and the cartilaginous plate must be thought of together as a secondary ossification center ("epiphysis") of the vertebral body ("diaphysis"), but Schmorl associates the cartilaginous plate with the disc It seems likely that this difference of opinion is largely a matter of terminology We are accustomed to consider the articular cartilage of a true joint as the remains of the cartilaginous epiphysis (Runge suggests the plain term "chondrophysis" or "remains of the rudimentary cartilage" as a substitute designation), but the articulation of two vertebral bodies is not a true joint Instead, it is accomplished by means of the disc which originates, developmentally, from the same elementary tissue as does the cartilaginous plate and, even after development is complete, remains closely related to that plate and to the bony vertebral rim (Sharpey's fibers) Moreover, the cartilaginous plate is fused with the vertebral plate (p 13) and is joined to the disc by the gradual transition of one tissue into another In contrast to the true joints, the amphiarthroses have no strict anatomic separation by an articular cartilage and an articular space This, as pointed out by Runge, would appear to confirm the opinion that the connection of the vertebral bodies by the discs represents a precursor of a true joint, and that the cartilaginous plate is to be considered as a part of the disc tissue The whole purpose of Schmorl and his school (aside from the facts of embryologic development and anatomy) is to clarify the nature of the pathologic processes which may involve

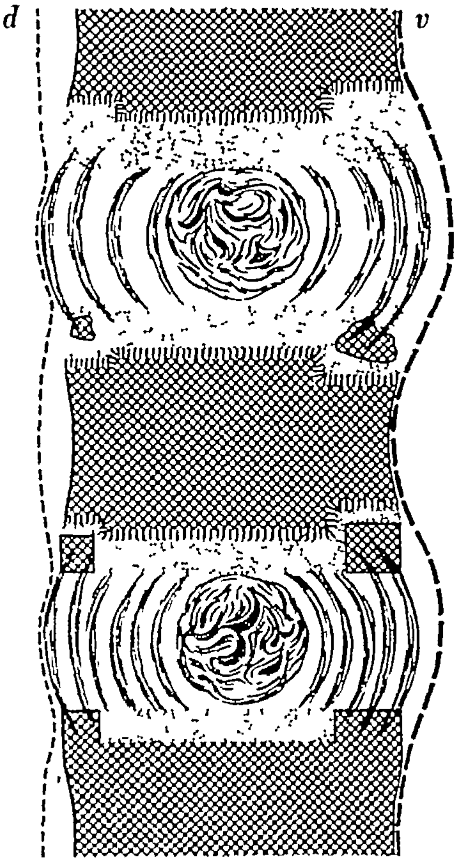


Fig 22 Schematic drawing of a sagittal section of the spine The dorsal surface (d) is to the left Four stages of the development of the vertebral rim are illustrated The cartilaginous plate of the uppermost vertebra and the cartilaginous rims form a solid cartilaginous structure (dotted) extending, dorsally and ventrally, into the recesses (figs 7 and 8) The dotted area beneath the uppermost disc shows the beginning ossification (cross hatched) of the vertebral rim (see figs 13 and 14) The ossification centers of the vertebral rim (shown beneath the cross hatched area representing the middle vertebral body) are better developed but remain separated from the body by a layer of cartilage (fig 17) The vertebral rim at the upper margin of the lowermost vertebra is now fused with the vertebral body, and Sharpey's fibers insert deeply into the vertebral rim Cartilage covers that part of the vertebral plate which lies within the circumference of the bony rim The anterior longitudinal ligament (thick broken line) is attached to the anterior and lateral surfaces of the vertebral bodies and spans the discs and the vertebral rims The posterior longitudinal ligament (broken line) is attached largely to the intervertebral discs

the junction of the disc and the vertebral body (W Weber) The closely united disc and the cartilaginous plate constitute the mobile, elastic and stress-absorbing segments of the vertebral column and form a physiologic unit in contradistinction to the rigid intervening vertebral bodies This fact must be borne in mind in all discussion, and for practical clinical purposes, the disc, once regarded as a sort of stepchild, should (in the sense in which Schmorl regards it) occupy the prominent place that it deserves

Of special importance in the radiographic study of the vertebral bodies is the structure and the nature of the spongiosa, since on it depends the variety of the shadows seen radiographically The term "spongiosa trabeculae" is not a correct one The spongiosa of the vertebral bodies, unlike that of the other bones, is not really trabeculated, but consists of thin bone plates intersecting each other and perforated by numerous openings varying from roughly circular to quadrangular in shape (fig 23) In a radiograph one may recognize the predominance of linear densities proceeding in the cephalocaudal direction, and these represent the bone lamellae (figs 4, 8, 16, 17, 19 and 21) The course of these plates varies somewhat in the different sections of the spine, depending on the direction of the principal functional stresses Alterations in these stresses, resulting from pathologic changes in the curvatures or the mobility of the spine, will alter the number and the direction of the bony plates of the spongiosa

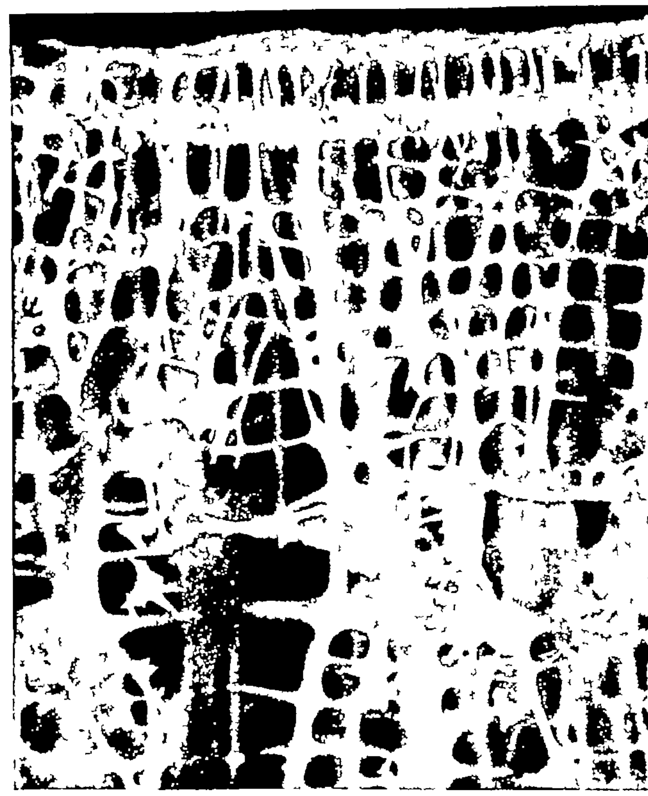


Fig 23 Slightly enlarged photograph of a sagittal section of a macerated lumbar body Trabeculation of normal spongiosa The spongiosa is composed of intersecting perforated plates Buttressing strands run beneath and parallel to the vertebral plates (cf fig 24)

Here we must discuss briefly a structural peculiarity sometimes observed in the spongiosa of a vertebral body (fig 24) Not infrequently, a radiograph of a vertebra will show a linear density closely paralleling the contour of the upper and lower surfaces and particularly marked in its midportion Such a density may be seen in the normal vertebral spongiosa in figure 23 These "double-contoured" vertebral plates seem to be of no very great importance Bohmig describes them as appearing only on the inferior vertebral plate in the young, but they may be seen on both plates in older subjects

Übermuth and Lyon consider this doubling of the vertebral plates quite striking Perhaps we should regard them as analagous to the transverse striations (growth-disturbance lines) seen near the articular extremities of long bones, following rickets and other disturbances of bone metabolism

The vertebrae of the cervical region have peculiar features not seen in other segments of the spine The five lower cervical vertebrae have bony ridges on each side of their superior surfaces, called uncinate or lunate processes These give to the superior surface the shape of a saddle, and the depth of this saddle decreases caudad

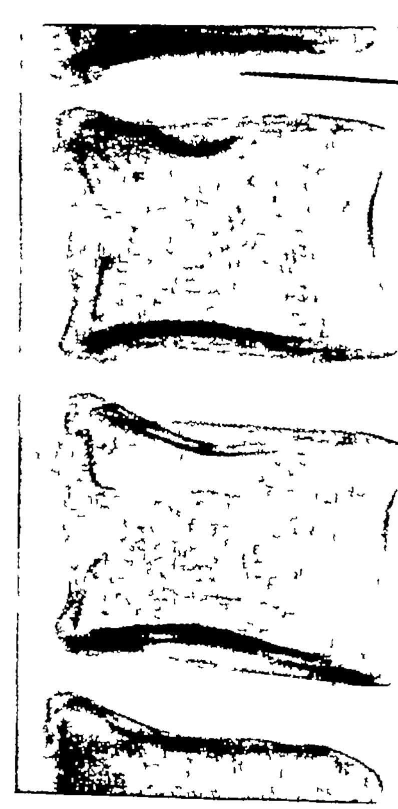


Fig 24

Fig 24 Lateral radiograph of the lumbar spine Man, age 34 The pin is in the first lumbar disc The edges of the upper and lower body surfaces show two parallel linear densities

Developmentally, the uncinate processes derive from the pedicles (Luschka), and they form, with the lateral aspect of the adjoining vertebral rim above, articulations called the small joints of Luschka[1] Whether these are true joints or gradually developed clefts in the tissue of the intervertebral discs has not been determined As the result of his investigations, Töndury believes that they are degenerative clefts that are sometimes filled by connective tissue containing fat. Occasionally, bilateral extension of a cleft leads to cleavage which produces a separation of the intervertebral disc into cranial and caudal halves The uncinate processes are of great importance because they are located so close to the discs, to the intervertebral foramina and the vertebral arteries (Chapter III O, p 149, fig 274)

The craniovertebral articulation, i e , the joint between the occiput and the atlas, and the articulation of the atlas with the axis also presents certain peculiarities (Chapter I H, p 23) The development and the anatomic aspects of these articulations are omitted here and may be found in textbooks of anatomy or in a resumé by Exner The radiologic examination of these joints presents many difficulties and calls for high quality technic, body section radiography frequently being the only examination of much value (Brocher, Fischedick, Gutmann, Sandberg et al)

B. The vertebral arches and their processes, the small vertebral joints and the apophyses

The ossification of the vertebral arches and their processes occurs independently from that of the vertebral bodies Töndury's investigations indicate that there are no actual enchondral ossification centers of the vertebral arches, and that each half of the vertebral arch ossifies from the perichondrium. The ossification centers in the arch of the atlas are recognizable at the end of the second embryonal month Gradually ossification proceeds caudad and, by the end of the fourth embryonal month, has occurred in all of the vertebral arches The ossification centers of each half of the arch enlarge gradually, replacing the cartilaginous arch, and the two halves finally approach each other posteriorly to form (in the course of the first year) the spinous process which has no ossification center of its own It does have an apophysis (fig 25) which will be discussed later (see translator's preface) (In the atlas and in the sacrum, the final bony union of the vertebral arches and the spinous processes is somewhat delayed and may not occur until the fourth, or even the sixth year) The other vertebral processes (the articular and transverse processes) lack ossification centers of their own, and become ossified by bony extensions from the ossification centers of the vertebral arches The ossification of the arches, which begins in the perichondrium on each side, extends anteriorly into the pedicle of the arch until it reaches the "arch epiphysis "[2] This arch epiphysis is an "intervening cartilage" which separates the two ossification centers from the vertebral body and which is still broad and clearly demonstrable in a radiograph of a newborn infant (fig 1). This cartilaginous zone between the vertebral body and the vertebral arch (intervening cartilage, also frequently called the "vertebral arch epiphysis") invaginates the vertebral body rather deeply (figs 5, 6 and 10), and the arch and the body become a single structure As a result, the vertebral arch and its roots form a considerable portion of the posterolateral aspect of the definitive vertebral body The bony union of the vertebral arch root and the vertebral body appears in the third to the sixth year but occasionally remnants of the intervening cartilage can be found in anatomic preparations until the age of 14, or even later

The vertebral arch surrounds two thirds of the vertebral canal while the remaining anterior third is formed by the posterior surface of the vertebral body Since this is described in the textbooks on anatomy, we will not discuss it here Neither shall we give detailed descriptions of the various processes of the vertebral body (articular, transverse and spinous processes), since their radiographic appearance and their characteristics are described in the standard textbooks

The "apophyseal joints," also called the small vertebral joints[3], should not be called "intervertebral joints," since this is a term frequently used to describe the intervertebral discs The small vertebral

[1] In the American literature these joints are also known as " lateral intervertebral joints (R Jackson), "covertebral joints " (L A Hadley), or " uncovertebral joints " (ed)

[2] In the American literature referred to as neurocentral synchondrosis or "neurocentral junction" (ed.).

[3] In the American literature these joints are also known as " posterior vertebral joints " or " zygoapophyseal joints " We believe that small vertebral joints' is a preferable designation (ed)

joints (one on each side) are formed by superior articular processes of one vertebra with the inferior articular processes of the next vertebra above and are actually hinge joints They may be visualized in a radiograph only when the x-ray beam is parallel to their articular surfaces This is noted, ordinarily, in a lateral film of the thoracic spine, where an articular interspace can be seen extending obliquely from above downward In the cervical spine the planes of the articular surfaces of the small vertebral joints are such that the direction of the beam is usually oblique in relation to the articular space, consequently, they are not visualized This is also true, more or less, in the lumbar area Details on special projections can be found in the usual radiologic textbooks (Fick, Goldthwait, Guntz, Lange et al) The use of tomography, or body-section radiography, frequently will permit better visualization

In recent years the importance of the menisci of the small vertebral joints has become better understood Although

Fig 25 (left) Lateral radiograph of the lumbar spine Man, age 22 The spinous processes are capped by apophyses which have begun to unite with the processes The arrow indicates similar small apophyses, still separated by cartilage, at the tips of the transverse processes

Fig 26 (right) Photograph of a section in a frontal plane across the atlanto-axial articulation Meniscus-like projections protrude into the joint space from both sides of the capsule of the joint Specimen and picture courtesy of Dr Emminger, Augsburg

recognized for some time (Schminke and Santo, Töndury) these joints have been described more recently in detail by Emminger (fig 26), who offers many illustrations of them in Zukschwerdt's book These menisci originate from the articular capsules of the small vertebral joints and extend into the articular spaces as, *e g* , in the interphalangeal joints, etc A fat pad and a meniscus of compact fibrous tissue fills the free space between the insertion of the capsule of the joint and the joint space Emminger found such "meniscus-like" structures between the occiput and the atlas, and between the first and the second cervical vertebrae Their significance will be discussed later (Chapter III M)

The secondary ossification centers of the apophyses* which, heretofore, have been given little attention, are of major significance in radiologic differential diagnosis They form at the ends of the processes of the vertebral arch during the growth period (eleventh to the fourteenth year), beginning as small ossification centers in the cartilaginous tips of the individual arch processes, and cap the bony ends of these processes (fig 25) At first, a cartilage layer separates them from the tips of the arch processes, but this cartilaginous layer gradually disappears, and ossification occurs, resulting in union with the arch processes This process is completed at approximately the completion of the growth period (at age 25) The chronologic sequence and the variability of their appearance is even

* "Apophysis" as used in this text will mean secondary ossification center pertaining to an osseous process (nonarticulating epiphysis, ed)

more unpredictable than that of the vertebral rims and this chronologic irregularity is particularly marked in the apophyses of the articular processes (p 46) There are also apophyses, of irregular development, for the mamillary processes of the lumbar region Small disc-shaped secondary ossification centers develop along the lateral masses of the sacrum during the period of growth, and these correspond, developmentally to the transverse processes of the sacral vertebrae Rarely, they cover each ala of the sacrum over its full length and are seen as uniform narrow bone plates, most of them are divided into several individual parts (Giraudi), one for the auricular surface and one for the caudal part of the lateral mass The spinous processes of the cervical spine are bifid because of the presence of two separate apophyses

C. The intervertebral disc

The mobility and more especially, the function of the spine depends primarily on the shape and the condition of the discs, and comprehensive knowledge of the structure of the spine is an indispensable prerequisite to the understanding of the pathologic processes which may occur The term, "intervertebral cleft," much used in the past, has recently and properly disappeared from the literature, since, by association, it suggests an actual cleft, a designation unsuitable for an intervertebral space filled with disc tissue The use of exact terms will serve as a reminder that the so-called "wide intervertebral disc" or "high intervertebral space" actually represents highly differentiated tissue of great physiologic importance

It can be shown clearly in a radiograph that during the growth period the width of the disc space varies with age In the newborn the disc spaces and ossification centers of the vertebral bodies are of approximately the same width (fig 1), while radiographs in later years show a gradual narrowing of the disc space as compared to that of the vertebral bodies, and when growth has been completed the average height of the disc is only about one third that of the adjacent vertebral body (fig 19) The previously described formation of the bony rim of the vertebral body is a contributing factor, since it is superimposed on the edge of the vertebral body as a slightly elevated ring, thus diminishing somewhat the width of the disc space, especially in a radiograph

Fick, Jacobi Schrader, Strasser, W Weber, and others have shown through detailed measurements that the intervertebral spaces do not have the same width in all sections of the spine The individual discs also show differences in height in their anterior and posterior portions These differences may be considerable, especially in the lumbar region, and are related to the spinal curvatures

The radiographic image of a normal disc space appears as a radiolucent band which is sharply limited by the opacity of the adjacent vertebral bodies In spite of the meagerness of the radiographic findings with which the clinician must content himself, we shall study (with photographic documentation) the basic anatomic structure of the intervertebral discs A thorough understanding of these structures is essential to the comprehension of the various pathologic processes which may involve them and to the radiologic interpretation of the changes produced, a subject which we shall discuss later

At the end of the period of intra-uterine life (or "the development of the embryo") the discs are composed essentially of hyaline cartilage surrounding the vestigial remains of the notochord, which ultimately forms the nucleus pulposus According to Broman the outermost layers of the disc tissue have an easily recognized fibrous structure, even in the cartilaginous stage Übermuth, however, is of the opinion that the transformation of the hyaline cartilage of the embryonic disc into the final fibrocartilaginous structure proceeds from the nucleus pulposus towards the periphery This opinion was contradicted frequently and recently it has been proven (Prader Töndury) that the fibrous elements of the outermost layers of the annulus fibrosus develop in the early embryonal stages, thus preparing for later functional strain As the result of their histologic studies Hirsch and Schajowicz conclude that the size and form of the final fibrous ring is the result of interstitial and marginal growth from the longitudinal ligaments of the spine, which form a sort of perichondrium for the intervertebral disc The significance of the developmental stages of the notochord may be found in numerous earlier publications (Dursy, Froriep, Kölliker Link Minot, Williams)

Büchner found that, in its early stage of development hypoxemia results in considerable disturbance of the development of the notochord, but how much the development of the actual intervertebral disc tissue is affected is not well understood (cf Chapters II A II A 8 IV A 1)

The progressive differentiations which accompany alterations in the statics of the vertebral column in an infant lead to the appearance of four permanent components of each disc a gelatinous nucleus (nucleus pulposus), a fibrous ring (annulus fibrosus) and two cartilaginous plates attached to the surfaces of the vertebral bodies An accompanying phenomenon is the progressive involution of the vascular structures of the embryonal disc, all of which disappear with the completion of growth (about age 25) The "vestigial remains of vessels" seen in some portions of the cartilaginous plates are of great significance as to pathologic processes, and later we will refer to this repeatedly The vascularization of the developing disc has been described by Böhmig, Ferguson and others

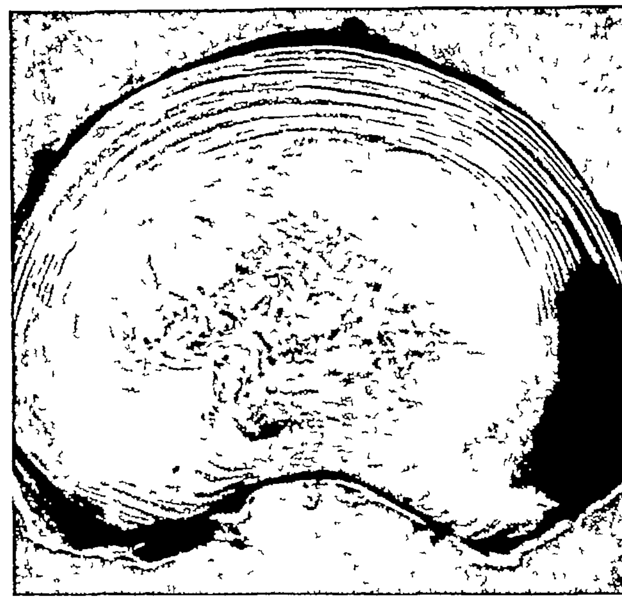


Fig 27 Photograph of a horizontal section through normal disc Distinct concentric layer structure of the annulus fibrosus The nucleus, stained by Schmorl's method, shows the clustered central lamellae

The cartilaginous plates, overlying the surfaces to which the discs are attached, are much thicker during the first years of life They constitute the parent tissue of the growing vertebral body, since the enchondral growth layer of the ossification centers of the vertebrae are located here (remnants of cartilage-anlage, chondrophysis, see p 8) We have already discussed (figs 7 and 22) the manner in which the cartilaginous plates project into the steplike recesses of the vertebral body edges, and the manner in which these "cartilaginous rims" gradually form the "bony rims" and unite firmly with the vertebral body Because of this process the superior and inferior vertebral plates in the fully developed spine are not entirely covered by the cartilaginous plates The cartilaginous plate ends, on all sides, at the inner margin of the elevated bony rim and is exactly as thick as the medial margin of the bony rim (fig 22) It is cemented onto the vertebral plate by a calcareous layer (Schmorl), leaving its minute perforations free to insure the nutrition of the disc Openings are found in the cartilaginous plates of adults, and these are called "ossification gaps" by Schmorl They are degenerative foci within the growth layer (described by Schwabe), the significance and origin of which has not been definitely explained The ossification gaps appear at about the time when vascular obliteration begins, but they are not located at the vascular passages Schajowicz regards the ossification gaps as fragmented calcium foci, the purpose of which is to provide immobilization for the very mobile cartilage which must become bone

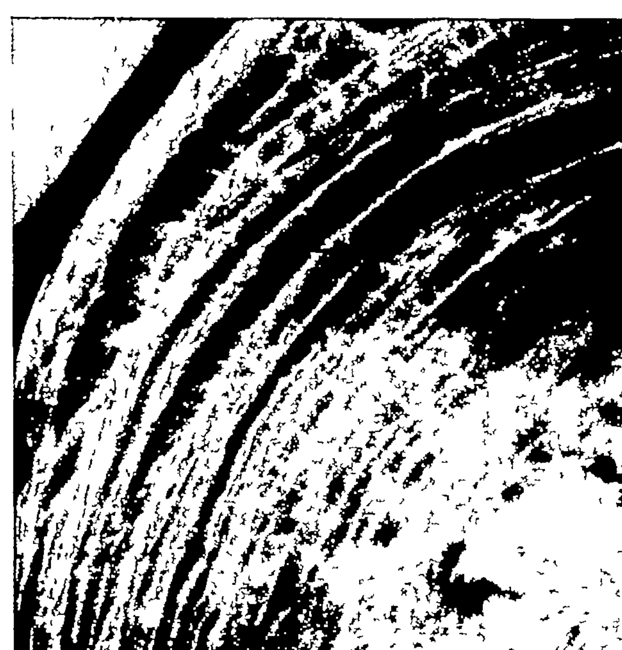


Fig 28 Slightly enlarged photograph of a horizontal section of the normal disc seen in figure 27

The fibrous, or lamellar, annulus forms the bulk of the intervertebral disc It consists of concentric spiral lamellae of closely packed cartilage fibers crossing each other, so that, when seen on section, alternate neighboring lamellae (spirals and contraspirals) appear, either dark or light, depending on the angle of incidence of the light (figs 27 and 28) Anteriorly, the fibrous ring is broad and the lamellae are well developed, while posteriorly, the lamellae are thinner and the fibrous ring is narrow, and this is true in both horizontal and cross sections The structure of the lamellae was described in detail by Fick, and Schmorl has demonstrated the existence of

"spanning fibers" between the lamellae He chose this name because disturbance in the course of the lamellae appears as soon as the spanning fibers are torn and destroyed Töndury was not able to demonstrate the spanning fibers The fibers in the region of the bony rim where there is no cartilaginous plate (here called Sharpey's fibers) penetrate into the bony rim (Roux Gebhardt, Schmorl) In this way a particularly firm union between the bony rim and the annulus fibrosus develops

Fig 29 Photograph of a sagittal section through a disc The stratification of the spinal fibers of the annulus fibrosus is well shown A section of the bony rim is seen on the left It is still separated from the vertebral body by a zone of cartilage

In a cross section in the frontal plane one can see clearly the symmetric bilateral arrangement of the lamellae The layers of the lamellae are relatively thick, take a curving course and are slightly convex laterally Some of the spanning fibers, arranged vertically to the course of the lamellae can be recognized by their distinct sheen In sagittal sections the arrangement of the fibers is not usually as symmetric as described here (fig 29), their course and thickness change as they approach the center, and the convexity is somewhat greater on the ventral than on the dorsal aspect In the vicinity of the nucleus pulposus, the course of the lamellae is closely related to the shape and position of the nucleus, as described below

The thickness of the individual lamellae varies in various sections of the same spine, and the lamellae in the anterior portions of the disc are usually thicker than those in the posterior portions

Fig 30 (left) Illustration by Luschka Center of nucleus opened to show the nuclear cavity (a)

Fig 31 (right) Photograph of a disc sectioned horizontally Removal of the gelatinous center to show the nuclear cavity

(fig 29) This is related essentially to differences in functional strain on the individual disc portions Fick found elastic fibers scattered between the lamellar rings

The nucleus pulposus of the disc develops from the remnants of the notochord, which remain in the disc space after regression of the notochord (fig 43) In the newborn infant its essential components are cells which gradually disappear in the normal course of growth Übermuth was unable to find any notochord cells in the nucleus pulposus after the completion of growth, while other authors maintain that they may be found in the nucleus up to the most advanced age Schwabe found such cells in the remnants of the sacral discs as late as the fifth decade One may see, in the nucleus pulposus of a young adult a network of agglomerated cell nuclei resembling the nuclei of the cells of the notochord The interstices of this network contain a gelatinous substance and the

whole complex (chorda reticulum) has been described by Sylven as a tridimensional lattice system The innermost layers of the fibrous ring gradually undergo liquefaction and become a mucoid material, and the innermost lamellae become fibrillated and project as fine villi into a cavity filled by a mucoid synovial fluid Portal was the first to describe this cavity in the interior of the nucleus pulposus, later examined in more detail and illustrated by Luschka (fig 30) On sections through juvenile discs, the nuclei of which contain fluid, one demonstrates easily the irregular cavity, with ramifications of the nucleus, by lifting the individual villi from the nucleus cavity (fig 31) The extent of the nucleus cavity can be well shown by the injection of a radiopaque material (figs 32—35) Such studies have been made in living subjects (p 148)

The water content of the discs has been repeatedly and thoroughly investigated, because of its morphologic and

Fig 32

Fig 33

Fig 34

Fig 35

Fig 32 (upper left) Lateral radiograph of the lumbar spine Man, age 47 The cavities of the nucleus have been injected with a radiopaque material Lamellar interstices may be seen, overlapping each other like an onion skin Traces of the radiopaque material can also be seen at the point of injection

Fig 33 (upper right) Lateral radiograph of a thoracic spine Man, age 47 Nuclear cavity injected as in fig 32 The extent and ramification of the cavity is greater than in the lumbar region

Fig 34 (lower left) Lateral radiograph of a lower thoracic spine Woman, age 53 Discography as in figures 32 and 33 Extent and arrangement of the cavity of the nucleus is somewhat different than that seen in the previous figures

Fig 35 Anteroposterior view of the specimen shown in figure 34

functional role. Keyes and Compere found that the water content of the discs was 88 per cent in a newborn infant, 80 per cent at age 12, and 70 per cent in a subject of 72. Detailed investigations were published by Puschel, of Schmorl's Institute, in which the differences in the water content of the nucleus and of the annulus fibrosus were given special consideration. These investigations showed that the individual discs of the same spine have the same water content, as far as normal discs are concerned. The nucleus pulposus contains more fluid than the annulus fibrosus. In the newborn infant the water content of the annulus fibrosus is 78 per cent, and that of the nucleus 88 per cent. This difference of 10 per cent decreases as life progresses, and the total water content of the discs also decreases with increasing age. In the third decade the annulus fibrosus contains about 70 per cent water and the nucleus 76 per cent. The annulus fibrosus retains a water content of about 70 per cent throughout life, but the water content in the nucleus decreases steadily to approach, more and more, that of the annulus fibrosus. The results of investigations as to the capacity for water uptake (swelling capacity) of the discs, in the various age periods, and the changes of elasticity thus conditioned, can be found in Göcke's paper. The considerable internal pressure inherent in the disc (particularly due to the intrinsic pressure [turgor] of the nucleus) has been measured by Petter. The pressure experiments of Hirsch and Nachemson yielded results of considerable interest as to the resistance of the disc tissue. Even when high pressures were employed, only insignificant compression of the disc was found. Using a pressure of 100 Kg. the height of the normal disc was reduced by 1.4 mm. and the width was increased by 0.75 mm., whereas the reduction in height of a degenerated disc was 2 mm. Rapidly changing stresses lead to oscillation of the disc. The disc has a great degree of adaptability, changing its form with any change in the position of the body. For this reason, Hirsch and Nachemson call the disc a dynamic system, because "the mass of the disc is in constant movement. Considering that the body is never absolutely still, there must be a constant displacement of the mass of the disc. It is a biomechanical phenomenon of constantly changing stresses in material taking place in fractions of a second, and is a result of the physiologic property of the material." They conclude that the biologic phenomena of the disc are greatly influenced by the mechanical stresses to which the disc is constantly subjected (Chapter IV C 1, E 1).

The disc tissue is not only subjected to mechanical stresses, but undergoes chemical processes which are also of importance. Ott has demonstrated the role of hyaluronidase in the water uptake capacity of the disc leading, possibly, to ruptures of the fibers of the annulus. This has been demonstrated experimentally (Naylor and Smare).

According to Charnley the hydrophil mucopolypeptides, present in the nucleus pulposus, are responsible for the remarkable ability of the disc to retain a high water content. For details see Hirsch, Makowsky, Schümmelfeder, Virgin.

The nerve supply of the disc is not well understood. Several investigators (Hirsch and Schajowicz, Jung and Brunschwieg, Keyes and Compere) could find neither nerve fibers nor nerve end apparatus. Roofe, Spurling and Granthan, however, found nerves in the fibrous rings of the fourth and fifth lumbar discs and in the posterior longitudinal ligament, apparently fibers coming from the second lumbar root (see Chapter I H, p. 23). Nerve fibers in the posterior layers of the annulus fibrosus in the lumbar region were demonstrated in 1949 by Wiberg and by Kuhlendahl in 1950. Thus far, nerve fibers in the inner layers of the annulus ring, or even in the nucleus pulposus, have been observed only by Tsukada.

D. The ligaments

The structure of the extensive ligamentous apparatus of the spine is sufficiently well known from textbooks of anatomy, therefore we shall dispense with detailed description. We will, however mention some specific features essential for the understanding of the pathologic processes of the spine. The anterior and posterior longitudinal ligaments, as well as the numerous small ligaments extending between the individual vertebral processes develop from the perichondral tissues.

The anterior longitudinal ligament covers the anterior and lateral surfaces of all of the vertebral bodies, and is composed of sections of varying length, extending from one vertebra to another. It is very firmly connected to the outer surfaces of the vertebral bodies and forms their periosteum. The intervertebral discs, however, are connected with the anterior longitudinal ligament only by

loose fibrous strands Most of the ligamentous strands arise from the anterior and lateral surfaces of the vertebral body in the area between the bony rims, spanning the discs and the vertebral rims (fig 22) The fibrous strands of this ligament contain only a few elastic fibers and are particularly thick in the portions which are attached to the outer surface of the vertebral bodies Bick reports that Lindblom found sensory nerve ends in the anterior longitudinal ligament (cf Chapter V C)

The posterior longitudinal ligament is narrower than the anterior (figs 36 and 37), but is thicker and contains more elastic fibers (Fick) It differs from the anterior longitudinal ligament in that it is firmly attached to the intervertebral discs and spans the slightly concave posterior surfaces of the vertebrae The posterior longitudinal ligament in the region of the discs is comparatively broad, but it soon attenuates and extends as a narrow band over the posterior surfaces of the vertebral bodies, to spread fan-like over each intervertebral disc Between the posterior longitudinal ligament and the posterior surfaces of the vertebral bodies lies a venous network which joins the vertebral veins Laterally, and attached to the posterior longitudinal ligament, is a thin layer of connective tissue, separating the longitudinal veins of the spinal canal from the dura mater Small arteries and numerous nerves pass between this connective tissue layer and the vertebral body, and Luschka thinks these nerves are responsible for the pain in vertebral diseases

The anterior and posterior longitudinal ligaments of the spine act as antagonists in movements of the vertebral column Henle believes the posterior longitudinal ligament also serves the purpose of protecting the spinal cord from the varying pressures of the venous network

In his handbook Fick gives a detailed description of the numerous other small spinal ligaments, especially those between the vertebral arch processes, those interested may refer to it In most cases, symptoms are related to these ligaments only when they are subject to pathologic calcification, since this results in rigidity of the affected spinal region or in constriction of the intervertebral foramina (Chapter III M)

The ligamenta flava located on the surface of the posterior bony wall of the vertebral canal are important, they are very elastic and serve to restrain the mobility of the small vertebral joints Their striking yellow color is due to the high elastin content of these fibers which form a dense network (Herzog) In the lumbar region, the yellow ligament is particularly thick (5 to 8 mm) and quite broad, but since this varies markedly, a diagnosis of "hypertrophy of the yellow ligament" must be made cautiously (Chapter IV B 2) Junge has given a detailed description of the yellow ligament

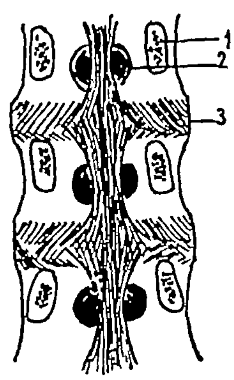


Fig 36

Fig 37

Fig 36 Diagrammatic drawing of a section of the specimen shown in figure 37 (1) section through the pedicles (2) vascular channel (3) disc

Fig 37 Photograph of the vertebral column of a young man after removal of the vertebral arches Posterior view The narrow posterior longitudinal ligament spans the vertebral bodies to be inserted fan-like into the discs The venous channels emerging from the vertebral bodies can be recognized on each side of the posterior longitudinal ligament

E. The intervertebral foramina

The intervertebral foramina, which are of great practical importance, are short tubular canals enclosing the nerve roots and vessels emerging from the neural canal Unfortunately, in the radiologic literature, their visualization and their appraisal have been given too little attention because of the difficulties of interpretation produced by the innumerable superimpositions of shadows seen in the radiograph In most regions the intervertebral foramina can be visualized in a lateral radiograph, although in the cervical spine they are best shown in oblique projections (Thoma) Their size and shape differs somewhat in the various regions of the spine

functional role Keyes and Compere found that the water content of the discs was 88 per cent in a newborn infant, 80 per cent at age 12, and 70 per cent in a subject of 72 Detailed investigations were published by Puschel, of Schmorl's Institute, in which the differences in the water content of the nucleus and of the annulus fibrosus were given special consideration These investigations showed that the individual discs of the same spine have the same water content, as far as normal discs are concerned The nucleus pulposus contains more fluid than the annulus fibrosus In the newborn infant the water content of the annulus fibrosus is 78 per cent, and that of the nucleus 88 per cent This difference of 10 per cent decreases as life progresses, and the total water content of the discs also decreases with increasing age In the third decade the annulus fibrosus contains about 70 per cent water and the nucleus 76 per cent The annulus fibrosus retains a water content of about 70 per cent throughout life, but the water content in the nucleus decreases steadily to approach, more and more, that of the annulus fibrosus The results of investigations as to the capacity for water uptake (swelling capacity) of the discs, in the various age periods, and the changes of elasticity thus conditioned, can be found in Göcke's paper The considerable internal pressure inherent in the disc (particularly due to the intrinsic pressure [turgor] of the nucleus) has been measured by Petter The pressure experiments of Hirsch and Nachemson yielded results of considerable interest as to the resistance of the disc tissue Even when high pressures were employed, only insignificant compression of the disc was found Using a pressure of 100 Kg the height of the normal disc was reduced by 1 4 mm and the width was increased by 0 75 mm , whereas the reduction in height of a degenerated disc was 2 mm Rapidly changing stresses lead to oscillation of the disc The disc has a great degree of adaptability, changing its form with any change in the position of the body For this reason, Hirsch and Nachemson call the disc a dynamic system, because "the mass of the disc is in constant movement Considering that the body is never absolutely still, there must be a constant displacement of the mass of the disc It is a biomechanical phenomenon of constantly changing stresses in material taking place in fractions of a second, and is a result of the physiologic property of the material" They conclude that the biologic phenomena of the disc are greatly influenced by the mechanical stresses to which the disc is constantly subjected (Chapter IV C 1, E 1)

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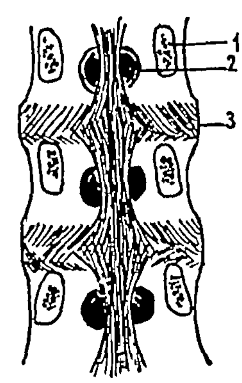

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It should be noted especially that, in the cervical region, the planes of the intervertebral foramen do not form right angles with the frontal plane, but are inclined at 30 degrees to the sagittal plane in the posterolateral direction Consequently, according to Thoma, in order to visualize these foramina, an oblique projection is necessary with the incident beam passing from before-backward (Barsony and Koppenstein) In such a projection, the outlines of the vertebral foramina approach the shape of a figure 8 and are somewhat wider above than below (fig 38) The first intervertebral foramen (between the atlas and the axis) is an exception to this rule, it has a longitudinal axis running in the anteroposterior direction and very closely resembles the atlanto-occipital foramen Pichler has given a detailed description of the form and the course of the intervertebral foramina of the cervical region

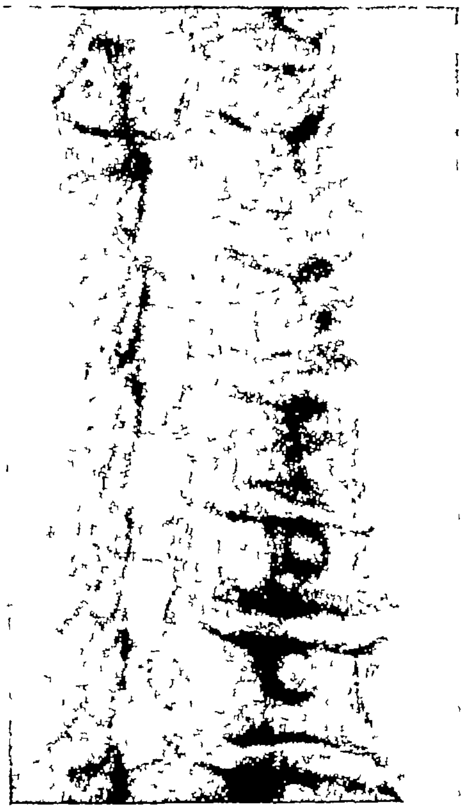


Fig 38 Right anterior oblique view of the cervical spine Woman, age 60 Normal size and shape of the intervertebral foramina Slight degree of spondylosis deformans with osteophytes on the anterior vertebral margins

It should be mentioned however that, Hyrtl to the contrary notwithstanding, we do not count the foramen between the occiput and the atlas as the first intervertebral foramen On the contrary, it seems better to begin the count with the foramen lying between the atlas and the axis Thus we have 24 foramina between the atlas-axis foramen and the sacrum Each intervertebral foramen is given the same number as the disc behind which it lies, with the vertebral body and its arch contributing mainly to its boundary

In the thoracic region a lateral projection with the arms raised offers the best visualization of the intervertebral foramina, since the incident beam is perpendicular to the sagittal plane The foramina in this region are ovoid in shape with their axes extending from above and posteriorly to below and anteriorly (fig 39) The superior vertebral notch, which forms the lower limit of the intervertebral foramen, is shallower in the thoracic region, thus the intervertebral foramen lies almost exactly behind the vertebra bearing its number The lower third, or even the lower half of the intervertebral foramen, is overshadowed by the head and neck of the rib (fig 39)

Because of the deeper superior vertebral notches, and the somewhat different orientation of the articular processes, the intervertebral foramina in the lumbar region have shapes resembling ear lobes (fig 40) The last presacral intervertebral foramen L5—S1 presents a different aspect, since the superior vertebral notch of S1 is shallow, and the articular processes are oriented differently because of the lumbosacral angle The size and shape of the intervertebral foramina of any given segment of the spine does not remain uniform, but changes gradually from segment to segment This is particularly true in the cervicothoracic region Beginning with the fifth intervertebral foramen, the plane of the foramen rotates gradually from the oblique position to the sagittal plane in the upper thoracic spine This is discussed at length in the work of Thoma

It is not sufficient to consider only the bony confines of the intervertebral foramen, since to a considerable degree, the soft tissues determine the actual lumen of the foramen Posteriorly, the caliber of the foramen is somewhat decreased by the ligamentum flavum bridging the small vertebral joint (fig 41 C) Anteriorly, the posterolateral border of the posterior longitudinal ligament impinges on the foramen, and this is true especially in the lumbar spine, although less so in the thoracic and the cervical region Von Lanz has discussed the shape and the contents of the intervertebral foramina and recently Landoldt has described the development of their walls and their contents The result of these investigations and the description of the contents of the intervertebral foramina (Duus and Kahlau, Krücke) will be of importance in various clinical considerations (Chapter III N, p 126)

F. Rate of growth in the various spinal regions

The longitudinal growth of the spine depends on its 48 growth zones, since each vertebral body has one cartilaginous growth layer on its upper and one on its lower surface The growth energy of the individual growth zones is quite small as compared with that of the femur, which has about the same length as the spine and has only two cartilaginous growth zones The rate of growth in the individual regions of the spine is variable The farther caudad a vertebra is located, the greater the growth in

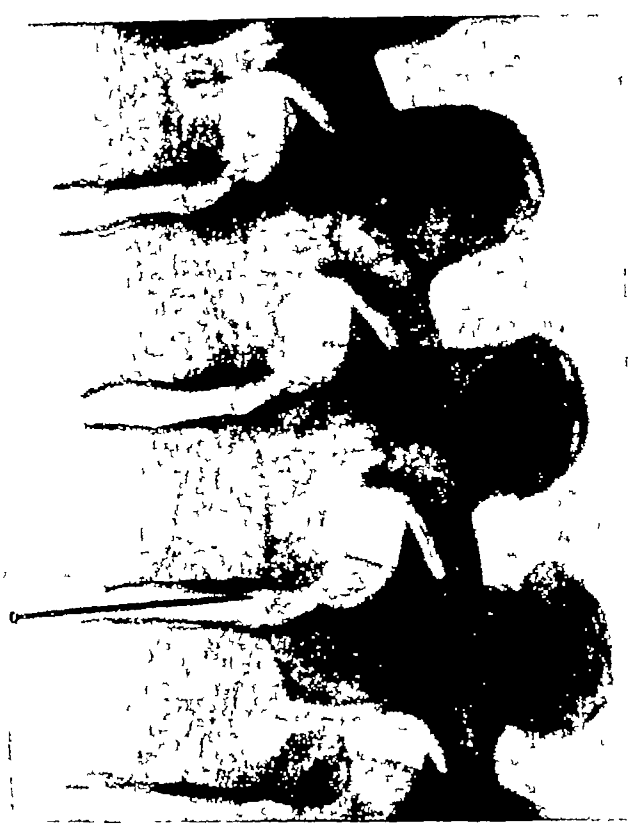


Fig 39 (left) Lateral radiograph of a sagittal section of part of the thoracic spine Man, age 69 Pin is in sixth thoracic disc Normal size and outline of the intervertebral foramina Superimposition of rib shadows

Fig 40 (right) Lateral view of the lumbar spine of a middle-aged man Normal shape of the intervertebral foramina There is usually a variation in the shape of the last presacral foramen

its height and breadth (Mau) In a newborn infant the midportion of the spine lies at the level of the seventh thoracic vertebra, but in the adult, it is at the level of T9 Disse, Ravenal, Bardeen, Frey, Langer, Moser et al have given detailed reports as to the rate of growth of the spine

From the third fetal month the spinal cord grows more slowly than does the vertebral column, resulting in the so-called ascensus medullae spinalis Consequently, the segments of the spinal cord in an adult are somewhat higher than the corresponding segments of the vertebral column

G. The adult spine as a whole

The shape of the spine changes, during its development, from the simple kyphotic curve of the entire spine seen in the embryo to the somewhat S-shaped curve of the adult, with kyphosis of the thoracic and lordosis of the cervical and lumbar region The normal spinal curves vary, depending on the constitutional type of the individual subject The shape of the vertebral bodies, as well as the shape of the intervertebral discs, influences the production of these curvatures, since the differences in the anterior and posterior height of the vertebral bodies and the intervertebral discs are essential

determining factors for these curves Many measurements have been made and recorded in the literature (Baladin, Fick, Hirschfeld, Horner, Jacobi, Luschka, Parof, Warner, Weber et al)

Many authors think that there is, moreover, a certain degree of physiologic scoliosis of the spine and Forkas gives exact measurements In 80 per cent of all human subjects he found a left scoliosis in the cervical and upper thoracic spine, a right scoliosis in the lower thoracic region and a left scoliosis in the lumbar spine Exactly the opposite was seen in the remaining 20 per cent The development of the physiologic lateral curvatures of the spine occurs after the sixth year, and these curvatures increase gradually with advancing age The fact that the trunk muscles are more strongly developed on the right is perhaps responsible for the direction of the curvatures

In addition to the physiologic curvatures of the spine (excluding the sacral region) the lumbosacral angle and the shape of the sacrum play significant parts in the shaping and the weight-bearing capacities of the spine This, which is important for the evaluation of radiographic findings and for the explanation of low back pain, will be dealt with in greater detail in a separate section (Chapter VI E)

The mobility of the spine depends, in part, on the extent of motion allowed by small vertebral joints, and, in part, on the role played by the intervertebral discs Since the orientation of the small vertebral joints varies greatly in the various spinal regions, the degree and direction of movement also varies Although the mobility of an individual pair of joints is not very great, the sum total of movement in a great number of superimposed joint pairs results in a considerable degree of total mobility Fick, Braus et al have made extensive investigations on spinal motion and the student can be referred to the literature Measurements made in recent years, using radiographs of living subjects, yielded results which are especially useful for clinical purposes (Bakke, Dittmar Husser, de Sèze and Djian) All possible bending and rotational movements of the spine were examined and measured Bakke compared his results, obtained on living subjects, with the anatomic investigations of Fick and Weber, and found that the extent of motion was essentially less in the living Bakke found the whole range of motion in the sagittal plane to be through 219 degrees, whereas Fick estimated 428 degrees and Weber 334 degrees Regarding the lateral mobility of the whole spine, Bakke reports 70 to 80 degrees in the living (radiographic measurements), while Fick found 105 in autopsy subjects after removal of the ribs Many additional data have been compiled by these authors

The important role played by the discs in the structure and mobility of the spine has been a frequent subject of investigations In this connection the interaction of the annulus fibrosus and the nucleus pulposus is of special significance (Dittmar, Göcke, Schrader et al) The nucleus pulposus must be conceived as the shock-absorbing and the weight-distributing section of the disc Even in the absence of stress the nucleus pulposus (owing to its inherent turgor which is the result of its water-binding power) exercises a certain degree of pressure and tension on the annulus fibrosus, as shown diagrammatically by Schrader Erlacher found in children a 2 per cent increase in the length of the spine when all fibrous rings were cut through and the turgor of the nucleus could thus exert its unhindered effect in cephalocaudal direction

The discs, therefore, not only act as elastic buffers built in between the vertebrae, but also serve to maintain spinal statics The tension, pull and pressure forces resulting from the interaction of the annulus fibrosus and the nucleus pulposus assist in the formation and the maintenance of spinal form and, at the same time, counteract the abnormal and excessive shearing and pulling forces brought about by the spinal movements One must always keep these factors in mind in examining and judging the total effect of pathologic processes For an exact evaluation a teleroentgenogram is necessary (Jäger), or radiographs taken as the spine is subjected to stress (Clement, Ingelmark), i e, while the subject is standing sitting (Jordan), and bending in various directions (Bourmer, Buetti-Bäuml, Erdmann, Franz, Gillespie, Hasner with Schalimtzek and Snorrason, Mardersteig, Rausch, Rostock, Salotti) This is because the conventional radiographs in the supine or lateral position do not yield sufficient information (Junghanns)

Radiographs of the entire spine (for which special equipment has been devised) have become of increasing importance (Baumann, Raspe, Sollmann) Cineradiography of the spine in motion,

which is thus far in an early phase of development (Janker, Rausch), may contribute to our knowledge of the functions and of the static problems of the spine The various special projections, such as are employed in the study of the atloido-occipital joints should be more commonly used by radiologists (Gutmann, Gutmann and Roller, Sandberg et al) and better detail must be constantly sought for (Übermuth et al)

Body section radiography should be employed more extensively for the visualization of those processes which are difficult to demonstrate by conventional methods but, thus far, such studies have been employed only rarely (Fischedick, Heep, Keller) Although "functional radiographic examination," as described above, is not in common use among radiologists and clinicians (cf pp 22, 157, 178), it should be more frequently employed

The physiology of the spine, by the arrangement of its rigid and elastic elements, combines, to a remarkable degree, stability and a wide range of very subtle movement The mobile and elastic disc tissues combine to produce an excellent buffer effect against a single trauma and against persistent weight pressure in the cephalocaudal direction, and to allow rotation of the spine All of the shearing forces which might endanger a column of such structure are successfully resisted by the structure of the annulus fibrosus, by the serration of the disc tissue and by the bony vertebral bodies, *e g* , by Sharpey's fibers at the rim and by the firm union between the cartilaginous plates and the vertebral body surfaces The S-shaped spinal curve, developing gradually as the upright position is assumed, also favorably influences the interception of shocks and the adaptation to various stresses

The transverse diameter and the volume of the vertebral body increases steadily from the cervical to the lumbar region, thus increasing the weight-bearing surface of each vertebral body Comparative anatomic studies show this to be true only in humans and to be connected definitely with the erect position In quadruped vertebrates the vertebra with the smallest transverse section is commonly a thoracic vertebra and the vertebral cross sections gradually increase in the cephalic as well as in the caudal direction

The spine is also a protective and weight-bearing organ of great importance The spinal cord is protected by its location in the vertebral canal, and the abdominal and thoracic cavities are protected from behind by the spine, which also serves as the basis of attachment for many of the internal organs It participates conclusively in the shaping of the chest and of the abdominal cavity Finally, the spine carries the head, the shoulder girdle and the arms, and transfers their weight and a large part of the weight of the trunk to the pelvis and to the legs The spine, however, is not only a weight-carrier, but because of the numerous ligaments and muscles which have their origin or insertion in the spine, it participates continuously in the movements of the whole body and in the movements and stresses of the extremities Thus, the spine is an organ under continuous stress with a central location, an organ important for the whole status of the body and its movements Viewed thus, trauma and pathologic processes have particularly serious consequences in the spine, and the changes in the spine may, in turn, be detrimental to other organs of our body (*e g* , kyphoscoliosis and cardiac diseases)

Within the limits of this monograph, it will be possible to refer to the musculature of the spine only casually and in passing This musculature not only permits the voluntary movements of the spine, but maintains the normal curvatures and controls the reaction of the vertebral column to the sudden stresses so frequent in everyday life Thus, the spine is under constant strain, and the fatigue which results affects unfavorably the maintenance of the normal spinal curvatures and, no doubt, produces in the structural components of the spine and its dependent organs such changes as, for example, senile kyphosis (Chapter VI A 3)

H. The motor segments of the vertebral column

Luschka considers the intervertebral discs to be among the amphiarthroses of the human body To make this a logical idea, the nucleus pulposus must be regarded as the articular cavity, the annulus fibrosus as the ligamentous apparatus, and the cartilaginous plates covering the superior and inferior surfaces of the vertebrae as equivalent to the articular cartilages The disc amphiarthroses

are of great importance not only for motion but also limitation of motion, as we have mentioned repeatedly However, for a general functional assessment of spinal mobility, we must go beyond the amphiarthrosis of the disc and consider the movement between two vertebrae as a complete unit Junghanns suggests the name "motor segment" (fig 41), if this is accepted, there will be 23 or 24 such segments (the two uppermost vertebrae actually have no intervertebral discs, see p 22) As functioning parts of the motor segments we must consider the intervertebral disc (with the nucleus pulposus, the annulus fibrosus, and the cartilaginous plates), the anterior and posterior longitudinal ligaments, the small vertebral joints and the ligamenta flava To this segment belong the contents of the spinal canal, the intervertebral foramina, and the spaces between the adjacent processes and the transverse processes The numerous ligaments between the various small joints and the extensor muscles of the back must be added We will see, later, how thoroughly all the individual components of this "motor segment" unit are interrelated A congenital or acquired defect affects all the components of the motor segment (possibly even several of them) depending on the size of the defect and the importance of the portion affected

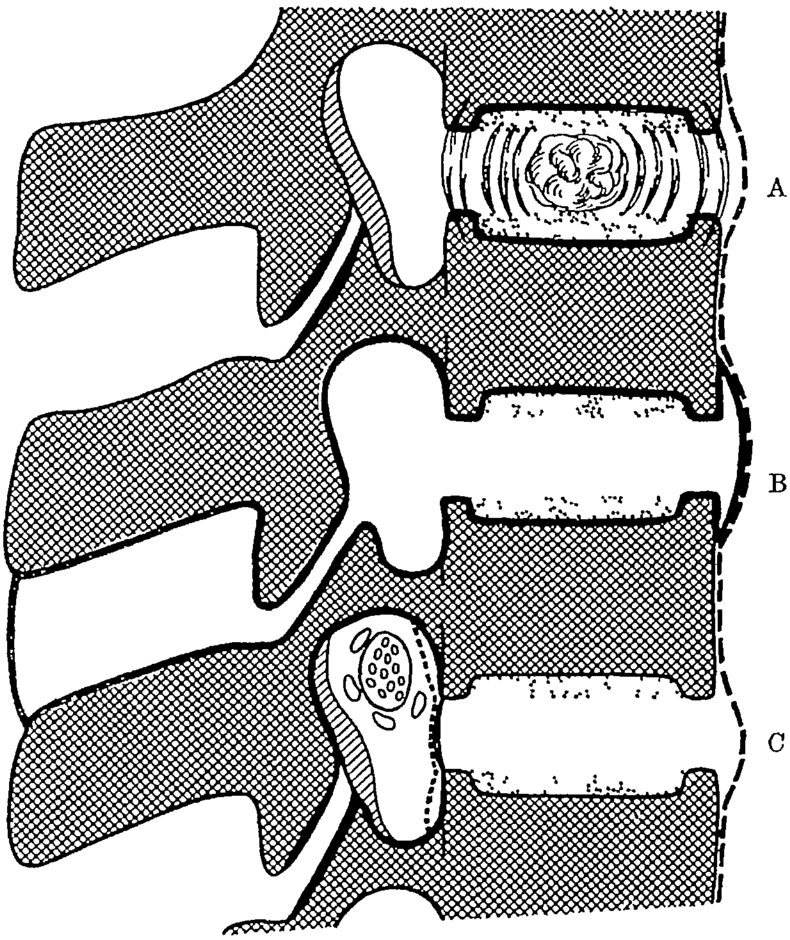


Fig 41 Schematic representation (A) disc amphiarthrosis (B) motor segment (C) intervertebral foramen

In the discussion of the small vertebral joints we have mentioned the importance of the motor segments in the over-all mobility of the spine This segmental mobility depends on the condition of the bony components of the spinal column, on the normal and pathologic deviations, and even on the extravertebral causes of limitation of movement (*e g*, muscular affections, rigidity of the thorax and similar conditions) This enumeration, however, by no means includes all of the elements entering into spinal mobility, the maintenance of the normal shape of the spine or those elements dependent on normal spinal function These would include, in addition to the extensor muscles, the iliopsoas and other muscles extending from the trunk to the limbs, the muscles of the shoulder girdle and the pelvis, the abdominal muscles and the thorax with its bones, ligaments and muscles The internal abdominal pressure, the respiratory capacity of the lungs and the tension produced by the internal organs which are attached to the spine, certainly play an important part The weight of the head and the weight-bearing capacity of the pelvis and lower limbs also influence the function of both the spine and, in particular, its motor segments

There exists a close anatomic and functional relation between the components of the motor segment and the intervertebral foramina which form a part of each segment These foramina are, in reality, little canals containing the vessels, the nerve roots and the connecting fibers of the sympathetic nerves, as described by Luschka In addition, he describes the sinuvertebral nerve originating near the spinal ganglion and containing a thin sympathetic filament, supplying the bony walls, the vascular elements and the fibrocellular tissues in the spinal canal The presence of nerve filaments in the posterior portions of the intervertebral discs of the lumbar portion of the spine (Chapter I D p 16), and their communication with the sympathetic system (p 156), explains

the frequency of lumbar pain (often called "lumbago") and the relationship between such symptoms and disorders of the autonomic system (Braun, Wiberg) More detailed anatomic investigations, however, will be necessary to explain the relation of back pain (*e g* , "lumbago") to disc changes Considering the intimate topographic relations between the intervertebral foramen and its contents and the posterior portion of the disc, the ligamentum flavum and the articular processes, one will understand that even minimal changes in these structures, or misalignment of motor segments may have serious consequences for the contents of the intervertebral foramen We shall discuss this question later

Familiarity with the 23 or 24 segments is essential for correct radiologic interpretation As we pass from purely anatomic considerations to those of physiology and pathology, the importance of the motor segment in functional radiography becomes apparent (p 21) Such an examination enables a meticulous observer to detect and to interpret the most trifling changes Radiographs made in various projections, including weight-bearing positions, and with lateral, forward and backward bending (with the pelvis fixed) will be most useful Body-section radiography will frequently be of assistance

After describing the normal anatomy of the various portions of the spine, we considered the various problems of dynamics and physiology ("The Adult Spine as a Whole", p 19) Careful study of the motor segments will persuade the student of the necessity of adding to an anatomic appraisal, meticulous observations as to normal and disturbed dynamics In the chapters on congenital variations and pathologic changes we shall not, therefore, confine ourselves to a description of changes which could be demonstrated by purely anatomicopathologic means and radiographic study, but shall consider, wherever we can, functional abnormalities, the importance of which is very great (Junghanns Arch klin Chir *267* 393, 1950) This method of approach will be rewarding to the clinician only if he adds to the physical findings and the conventional radiologic study a "functional radiography" (see pp 21, 130, 157, 178)

The two uppermost motor segments, which have no intervertebral discs, are of especial importance The articulations between the occiput and the atlas, and between the atlas and the axis become of increasing importance as the technical means of studying them are improved (Gutmann, Sandberg, cf Chapters I A, III G 1, H 4, IV B 4) Our improved technics make it possible for us to understand these articulations and their disturbances, and to recognize the numerous variants which may be encountered (Glogowski) In recent years a great volume of literature has appeared dealing with the problems of these articulations and the value of manipulative therapy (Brocher, Decker and associates, Exner, Glogowski, Lindemann and Kuhlendahl, Matzdorf, Säker, Sander, Sollmann, Zukschwerdt et al)

II. Congenital Anomalies of the Spine

The numerous congenital anomalies of the spine are best understood by recalling the complexity of the elements which compose a vertebra, the number of vertebrae which make up the spine, and the fact that each of these building-blocks (the vertebral body, the arch and its process, the rib anlage and the secondary ossification centers) is developed independently Cartilage formation, ossification and the definitive development of the various elements occurs during varying periods, some elements which, originally, were fused (the apophyses of the vertebral arches and the rudimentary ribs) finally separate into various spinal segments while others remain fused Others, divided in the early stages of development (the vertebral bodies and the arches), fuse in a later stage Moreover, the transformation of a primitive vertebra into a definitive form is accompanied by segmental displacement during which the two hemivertebrae (right and left) are quite independent Developmental defects may occur during any period and at any level, and may induce a disturbance in another element with which it is connected functionally Various disorders may occur in any spinal segment simultaneously or at different developmental stages and may affect the functioning of the spine It is not surprising, then, that a great number of congenital spinal anomalies still lack a rational explanation, and there is urgent need for a classification of these anomalies, many of which cannot be demonstrated radiographically An embryologic basis for the classification of the congenital anomalies of the spine and a critical review of the literature is offered by Junghanns in "Pathology of the Spine" in the Handbuch der speziellen Pathologischen Anatomie, vol 11, sec 4, p 216ff and Arch Orthop Chir *38* 1, 1937

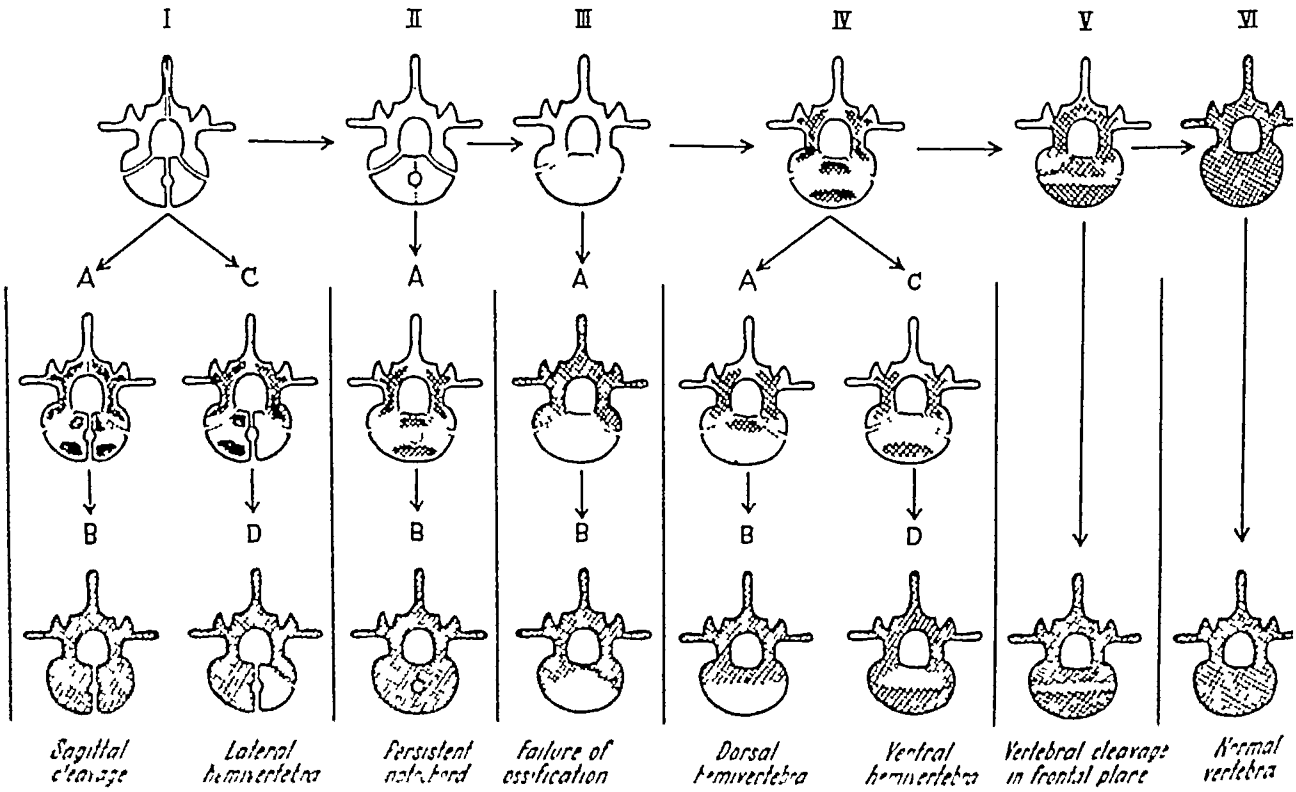


Fig 42 Stages in the development of a vertebra Variations and anomalies (second and third rows) Ossification is indicated by cross hatching (after Junghanns)

Putti's concept of a "primitive vertebra" was developed further by Diethelm and Junghanns who laid emphasis on the presence of a cleft in the frontal plane of the vertebral body (fig 42) Schinz and Tondury contributed greatly to our knowledge of the early phase of vertebral ossification Histologic study of the various phases of the development of the spine and, in particular, gross and microscopic studies of the various known anomalies will allow final clarification of this problem

The correct interpretation of radiographic material requires complete familiarity with the various congenital spinal anomalies since, without it, differentiation from acquired pathologic conditions is almost impossible The differential diagnosis of congenital and acquired block vertebra, fracture or congenital dehiscence of a vertebral body or its arch, hemivertebra of congenital origin and one resulting from partial destruction by an infectious or a neoplastic process is a diagnostic problem insoluble without complete familiarity with the various developmental anomalies of the spine The literature offers numerous examples (Junghanns, Übermuth, Weienskiold, Wustmann) and one may add to them readily by the study of available radiographic material Since the anomalous spine is quite vulnerable to stress and to disease (Klioner, Willich), differential diagnosis is likely to be difficult, especially in older individuals The distinction between a congenital and acquired anomaly may pose a delicate medicolegal problem, as well as a problem of therapeutic management Some of the spinal anomalies (*e g*, spondylolisthesis) result in spatial changes in the pelvis, and these are of interest to the obstetrician (Györgi, Kirchhoff) The association of anomalies of the spine and those of the urogenital apparatus or the intestinal tract is not infrequent (Malti, Nuvoli and Fanamo, Kazmarek)

The series formed by the alternating superimposition of vertebral bodies and intervertebral discs obeys different laws of development than the series composed of the vertebral arches and their processes The anomalies which occur in these series differ and will be described separately

A. Anomalies of the vertebral bodies and the discs

The notochord plays an important embryologic role in the development of the vertebral bodies and the discs Because of its craniocaudal course, the developmental anomalies of the vertebral column are also oriented in a craniocaudal direction (vertical dehiscence of the vertebral bodies, expansion of the discs in the paranuclear regions both above and below, etc) The spinal segmentation which results in the formation of the vertebral bodies and the discs takes place, on the contrary, in the horizontal plane The notochord disappears at the level of the vertebral body but persists at the disc level as a remnant of the notochord or basic substance of the nucleus pulposus (fig 43) The third factor influencing the development of the vertebrae and the discs is constituted by the blood vessels, which penetrate the vertebral bodies and which are concerned with ossification In the consideration of the developmental variations of the body-disc series, one must keep in mind three essential factors the notochord, segmentation and vascularization, any one of which or any combination of which may affect the developmental process

The animal experiments of Theiler (Institute of Töndury) indicate that the notochord plays a part in the segmentation process before bone

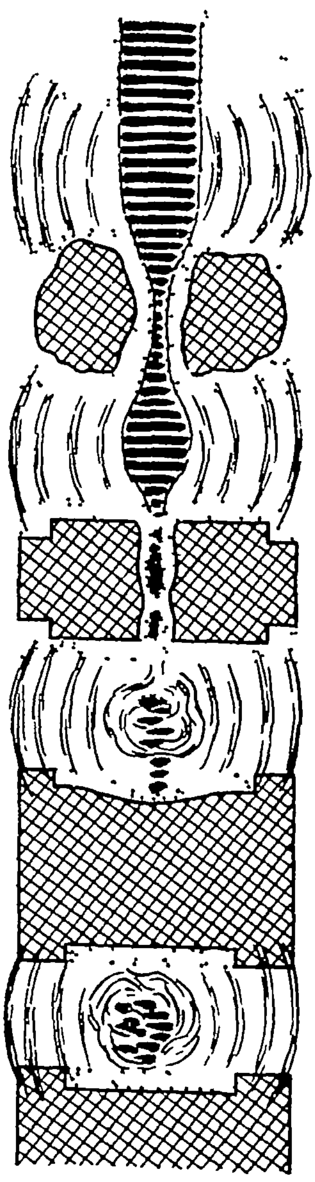


Fig 43

Fig 43

Diagrammatic representation of the regression of the notochord (in red) In the upper part of the diagram the notochord passes through the vertebral body and the disc With the appearance of the ossification centers (cross-hatching), constriction of the notochord occurs until only a remnant of it persists in the center of the disc The cartilaginous plate exhibits thinning and a slight depression in its center, where the notochord passed through the vertebral body (cf figs 57, 244—247 and 359)

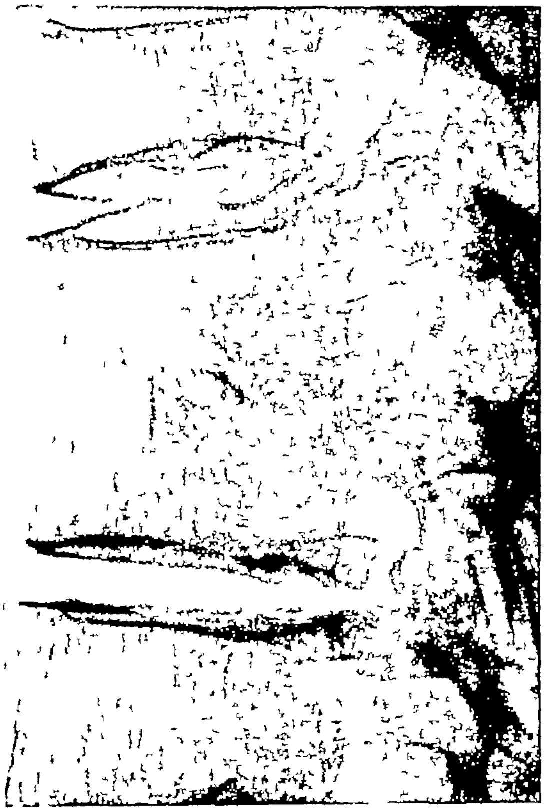


Fig 44 Lateral radiograph of the mid-thoracic spine of a woman, age 68 T8 and T9 form a congenital block vertebra with absence of the intervertebral disc

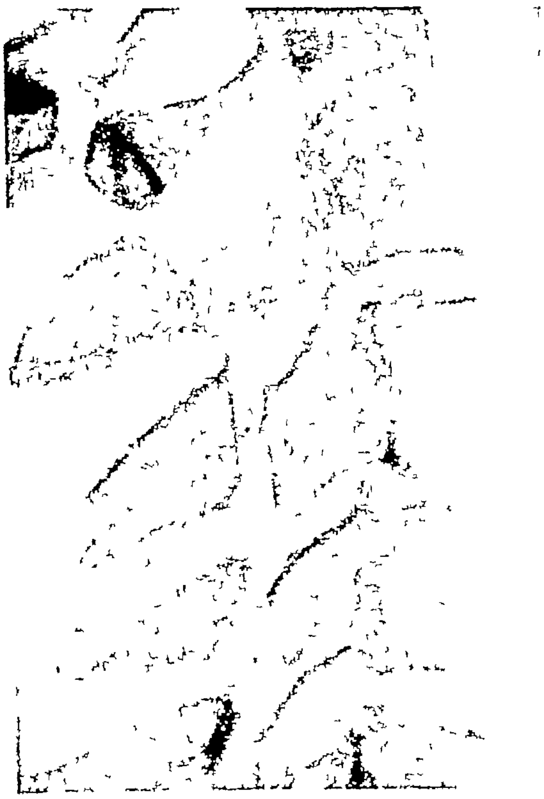


Fig 45 Lateral radiograph of a sagittal section of the cervical spine of a man, age 45 C3 and C4 form a congenital block vertebra, with fusion of both the spinous and the articular processes

formation occurs Töndury summarizes the experimental work of his associates thus, "The notochord is entirely responsible for the normal arrangement of the blastema of the spine Without it, there will be no normal development of the spine which, instead, will be only an unorganized mass of cartilage Once the arrangement of the primitive spine has occurred, the elastic cells of the notochord, then the segments of the notochord, and finally the nucleus pulposus, produce the normal disc differentiation With regression of the notochord, hyaline cartilage forms to occupy the intervertebral regions An abnormal displacement of the notochord will result in asymmetric development of the disc and formation of block vertebra will occur" (Additional bibliography Probst, Rathke, Seifert)

Büchner has suggested that maternal disease may induce hypoxemia in the developing embryo, resulting in malformation of the notochord, with an anomalous development of the entire body-disc series (cf Chapters I C, II A 9, IV C 1)

Figure 42 presents a schema of the vertebral anomalies which occur in the various developmental stages We will have occasion to refer repeatedly to this schema

1. Congenital block vertebra

The metameric arrangement of the vertebral body-disc series in the early stage of development is such that the middle one-third of the primitive segment becomes, finally, an intervertebral disc The upper and the lower thirds each represent a half vertebral body, *i e*, the lowermost third of a primitive segment and the uppermost third of the segment below it constitute a future vertebral body with the vessels penetrating the primitive cartilage in the plane separating the two primitive segments Thus, in the fully developed vertebra, these vessels occupy the mid-portion of the vertebral body, and are recognizable radiographically as linear radiolucencies ("Bands of Hahn," p 2 fig 1) Disturbance of the segmentation process results in the appearance of numerical anomalies of the vertebrae and especially in the formation of "block vertebra" Radiographically a block vertebra may exhibit continuous trabeculation throughout the fused segments (figs 44 and 45), or there may be recognized a discrete line of separation which represents a remnant of disc tissue (fig 46), usually demonstrable in the anatomic specimen The presence of a block vertebra does not alter the length of the spine, nor does it lead to any deformity The fusion however, of a considerable number of vertebral bodies with a consequent fixation of a significant section of the spine may result in quite marked reduction in the length of the vertebral column (Bakke, Bauer, Bülow-Hansen, Walther, Voltz,

Langhof, Lenk, Neustadt, Overton and Chormley, Pan, Radulescu, Rokitansky, Sorrel, Legrand-Lambling and Nabert and others) Such a change reflects, probably, premature arrest in the growth zones or the absence of such zones in several vertebral bodies

Bézi has proposed the term "assimilation" for the congenital form of block vertebra, and "synostosis" for the acquired form Drehmann believes that congenital block vertebra does not result from fusion, but from a defect in "segmental differentiation" Valentin and Putscher, however, consider congenital block vertebra to result from either slow or rapid absorption of the disc, or destruction of the disc after differentiation has already occurred Overgaard regards fusion as a regressive disc change occurring at the end of the growth period

Congenital block vertebra may involve only the body-disc series, but frequently fusion of the related vertebral arches occurs (Brocher) and, in such instances, disturbance of segmentation must be regarded as an etiologic factor in the production of congenital block vertebra (fig 45) It is conceivable that fusion of the related vertebral bodies occurred subsequent to fusion of the arches as a result of lack of motion with subsequent ossification of an interposed disc Working with experimental animals and carrying out the Albee operation (spinal fusion), Haas produced fusion of the vertebral arches with a consequent arrest of growth of the vertebral bodies and with reduction in the vertical diameter of the discs and changes in the vertebral rims From this it would appear that fusion of the vertebral arches has a marked influence on the growth of the body-disc series

Fig 46 Lateral radiograph of a sagittal section of the cervical spine of a woman, age 56 Congenital synostosis of two vertebrae including their spinous and articular processes Remnants of disc tissue are seen The intervertebral foramen are narrowed

We may recall, here, the fusion of the sacral vertebrae which, in the embryonal stage, are separate vertebrae with interposed discs separating them Remnants of disc tissue are sometimes encountered long after birth, especially in the upper portion of the sacrum The process of the development of the sacrum and the accompanying disappearance of disc tissue is well described by Schwabe, and Angerer has pointed out that similar regressive changes occur in the coccyx Fusion of the sacral vertebrae may be recognized, radiographically, as horizontal linear radiolucencies resembling those seen in block vertebra (fig 46) The differentiation between a fracture line and a disc remnant may be difficult (For detailed studies, including radiographs and bibliography, see Giraudi)

2. Cleft vertebra in the sagittal plane

Sagittal cleavage of one or more vertebral bodies, with production of one or more pairs of hemivertebrae, is a developmental error encountered not only in nonviable monsters but in living individuals of any age (fig 42, I B) It results from sagittal division of the notochord (Budde, Feller, Sternberg et al), appears in an early developmental stage and is associated frequently with malformation of the gastrointestinal tract and the central nervous system (Budde, Chapuis, Feller and Sternberg, Hartmann, Kolmer, Korff, Rotering et al) Extensive changes, involving several vertebrae, are incompatible with life (fig 106) Only isolated instances of cleft vertebrae are of clinical importance (van Assen, Blount, Frets, Gogoy, Hanson, Harrenstein, Hartmann, Korvin, Lange, W Muller, Osten-Sacken, Reisner, Sereghi et al) The defect is not a simple sagittal cleft, but a cylindrical space extending from above downward through the vestigial remains of the notochord (figs 47 and 48) From this central excavation, a cleft filled with cartilage extends anteriorly and posteriorly in the sagittal plane (fig 42, I B) The vertebral surfaces are depressed and assume a funnel shape, and the intervertebral discs communicate with each other In an anteroposterior radiograph, such a vertebra resembles a butterfly with outstretched wings (fig 49, "butterfly vertebra") Stress produces a lateral spread of the "butterfly vertebra" making it broader than the

Fig 47 Sagittal cleft in the last presacral vertebra ("butterfly vertebra") Hemisacralization Compensatory protrusion of the base of the sacrum into the cleft (after Frets)

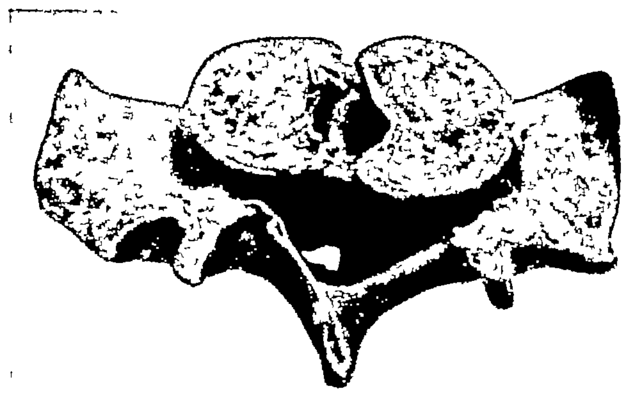


Fig 48 Same specimen as in figure 47 seen from above Note the primitive canal for the notochord (cf fig 42 I B, after Frets)

adjacent vertebral bodies (Sereghi), Hartmann has observed this feature in the fetus Growth disturbance may reduce the height of such a vertebra, especially its anterior portion where the stresses are greater Mild kyphosis, or even acute angulation may result from disturbed growth "Congenital kyphosis" may be produced from cleavage of a vertebral body in the sagittal plane (van Assen, Bauer, Güntz, Harrenstein, W Müller and others)

Sagittal dehiscence of a vertebral body may assume the aspect of an anterior spina bifida with meningocele, the clinical consequences of which are similar to those of posterior meningocele The defect occurs most frequently in the sacral region (Lüth, Osten-Sacken et al) The small meningeal herniation into the sacral vertebrae known as "spina bifida incompleta" or as "sacral cyst" (Kleiner) will be discussed later (p 36)

Fig 49 "Butterfly" configuration of L3 Central depression and lateral spread of the vertebral body (Sereghi's case)

3. Unilateral hemivertebra

The problem of unilateral hemivertebra, left or right, isolated or combined with other vertebral anomalies, is a very controversial one At present, one may not state definitely whether it results from a defect in the cartilage anlage, or is due to an arrest in the process of ossification Perhaps disturbed vascularization of one-half of a vertebra is responsible for the anomaly (Feller and Sternberg, Junghanns, W Müller Naegeli Niehues, Rosenberg) The early ossification center of unilateral vertebra is, at first, spherical and later, cubical One-half of the center vertebra remains cartilaginous and even in the embryonal stage has less height than the osseous half A moderate scoliosis results, becoming more apparent after birth (congenital scoliosis) The ossification center, originally cubical, becomes cuneiform in shape with its base directed laterally and its apex reaching or extending beyond the sagittal plane (fig 106) thus producing a unilateral wedge-shaped congenital hemi

vertebra This isolated anomaly is demonstrated clearly in an anteroposterior radiograph but, with multiple anomalies, and with scolioses and kyphoses, the picture becomes very complex (fig 106 and 108) The numerous references to this anomaly include Calvetti, Fusari, Gonzales-Aguilar, Haffner, Knapper, Lohmuller, W Müller, Novak, Perrot and Babaiantz, Reccandte Savés, Siciliani, Willich and others

4. Hemivertebra resulting from segmental displacement

As described previously, the embryonal vertebral column consists of a right and a left half (p 27, 28), and persistence of this primitive stage results in sagittal cleavage of the vertebral bodies (fig 42, I A, I B) In a very early stage of development, i e , during the transformation of the primitive into the definitive segments, metameric displacements of the segments may interrupt the entire process and result in vertebral anomalies This metameric segmental displacement may extend over a considerable portion of the spine, or may involve only a few segments The importance of such a "hemimetameric segmental shift" has been emphasized by Lehmann-Facius At each end of the area of "hemimetameric segmental shift," there remains a half-segment which, by the process described above, becomes a cuneiform hemivertebra (fig 50) Metameric segmental displacement seems to be responsible for a variety of mismatched hemivertebrae, illustrated in a schematic representation by W Muller Usually, there is an accompanying abnormality of the ribs and the vertebral arches, and block vertebrae are very common The combination of these multiple anomalies creates so complex a picture that it is scarcely possible to distinguish one from another If a person with such extensive defects survives, his spine will exhibit marked deformity produced by numerous hemivertebrae It is to be noted that the deformity produced by a unilateral hemivertebra is by no means compensated by an opposing hemivertebra This is because they do not have identical shapes since, located at different levels, they were subjected to different stresses during the growth period In such cases, the evaluation of trauma in the presence of multiple anomalies becomes very difficult and poses a medicolegal problem of some importance

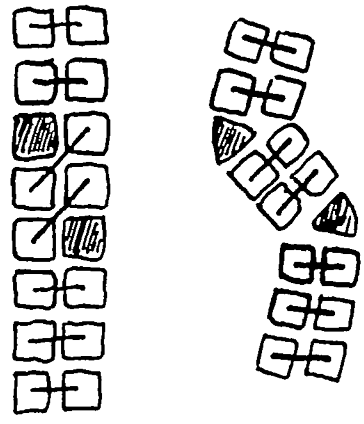


Fig 50 Schematic representation of metameric segmental displacement (A) hemivertebrae cross-hatched (B) wedging of hemivertebrae and the production of scoliosis

5a. Absence of vertebral body ossification

The lack of ossification of a vertebral body is a rare anomaly, and one that we believe to be due to vascular aplasia (fig 42 III A) During the process of development a nonossified vertebra may give rise to a gibbus deformity (congenital kyphosis) since the cartilaginous tissue is unable to withstand the static pressure of the other vertebrae Sometimes the pedicles, which normally participate in the formation of the posterolateral portions of the vertebral body (fig 10), continue to grow and to fuse in front of the spinal cord, thus continuing the anterior wall of the vertebral canal Thus there is produced a small dorsal hemivertebra (fig 42, III B, Bauer, van Schrick et al)

5b. Vertebral agenesis

The absence of a vertebral body with preservation of the vertebral arch was considered as a theoretic possibility by Putti, who referred to it as "asoma " Pursuing this theory, Diethelm described the case of a girl 2½ years old with absence of the body of the third lumbar vertebra and with persistence of the neural arch The agenesis was first recognized radiographically and later at autopsy He has pointed to similar cases in the literature (Braun, Feller and Sternberg, Jachens, and others) Diethelm's "disc tissue," which he seems to have identified anterior to the vertebral arches and fused around the vertebral canal, may represent only the failure of the residual cartilage of the primitive vertebra to ossify and subsequently transformed by static stresses during the two and one-half years of the child's life The rarity of references does not permit the elucidation of the problem

Congenital absence of the odontoid process is a very rare anomaly. Embryologically, the odontoid represents the body of the atlas, and it is difficult to decide whether its absence is due to agenesis, or to nonossification of the primitive cartilaginous vertebra. Roberts has described the absence of the odontoid in a 20 year old male, with traumatic dislocation of the atlas and with narrowing of the vertebral canal. Lombard and Le Génissel have reported a similar case.

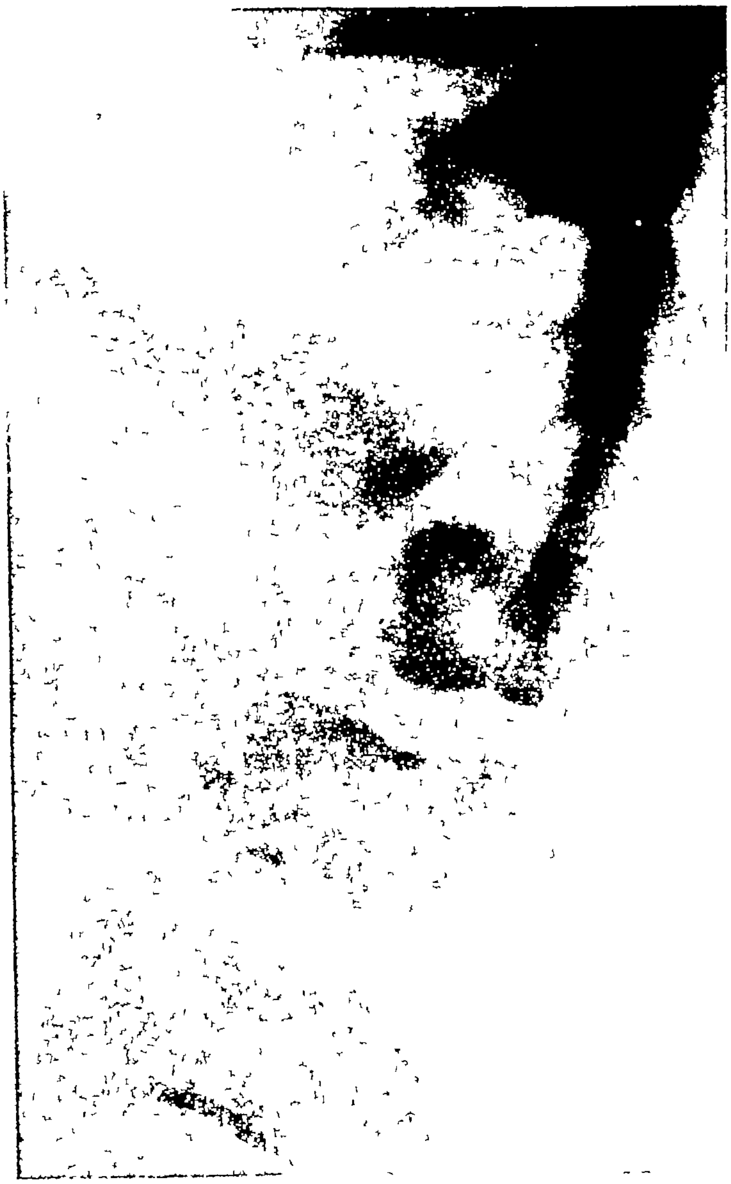


Fig 51 Lateral radiograph of the spine of a boy, age 15. Dorsal hemivertebra (L1) with formation of kyphosis

Agenesis or aplasia of large portions of the spine has been reported, usually involving not only the vertebral bodies, but their appendages. The lower sections of the spine are most often affected. These conditions result from the presence of a defective anlage for the development of the spine and are nearly always associated with extensive malformations of the central nervous system, the gastrointestinal tract, the genitourinary tract, the pelvis and the lower extremities (sirenomelus). The absence of large segments of the lower spine is incompatible with life (stillbirth). The radiologist and the clinician see cases with less extensive malformations: hemisacrum with malformed pelvis, and other anomalies of the sacrum. Attempted embryologic classification of these anomalies is beset by extreme difficulties and is of great complexity (Diethelm). (Bibliography: Boos, Castronovo, Feller and Sternberg, Güntz, Hamsa, Kienböck and Zimmer, J. Muller, Rocher and Roudil, Sinclair, Stupnicki, Valentin et al.)

6. Dorsal and ventral hemivertebrae

Compared with the great number of publications on the subject of cleft vertebrae in the sagittal plane, and the occurrence of unilateral hemivertebrae, there is a rather small number dealing with ossification of the posterior half of a vertebral body with the anterior half remaining fibro-cartilaginous. This is the anomaly called "dorsal hemivertebra" by Junghanns, "hemispondylus posterior" by Bakke, and "microspondylie" by Dreyfuss. Novak has suggested the term "hemispondylia sagittale," but this seems to be rather confusing. Numerous authors have pointed out that this anomaly is among the causes of congenital kyphosis. Bibliographß: Arnt, Bauer, Brocher, Drehmann, Göb, Kienböck, Lindemann, Schapira, v. Schrick, Wollenberg, Zanoli.

The embryogenesis of the spine demonstrates that ossification of a vertebral body is preceded by vascularization of the primitive cartilaginous vertebra, with subsequent appearance of two ossification centers, the one ventral, and the other dorsal (fig 42, IV). This process, studied earlier by Schaffer, has been described in a richly illustrated work by Schinz and Töndury. The dorsal ossification center is, at first, the larger of the two and displaces the notochord forward. Formerly, it was believed that this anomaly represented an arrest of development of the ventral ossification center by impaired vascularization. The role of vascularization is of great importance in the process of vertebral osteogenesis. Faulty vascularization results in the nonappearance of the ventral ossi-

fication center, and hence, ossification of the anterior portion of the vertebral body does not occur The cartilaginous portion, persisting as fibrocartilaginous tissue, is subjected to static pressures and the ossified posterior portion remains as a dorsal hemivertebra

The presence of a dorsal hemivertebra produces kyphosis of the spine, while a unilateral hemivertebra results in scoliosis (fig 52) The dorsal ossification center, at first cubical in form, fuses with the pedicles of the vertebral arch and, under the pressure of the superimposed vertebrae, assumes a cuneiform shape Compensatory increase in the anterior stature of the vertebral bodies above and below is not infrequently observed (fig 52) The anterior portion of the fibrocartilaginous tissue may undergo such complete obliteration that the superadjacent and subadjacent vertebrae may be in contact at their anterior margins (fig 52) The pressure of the vertebral column results in backward displacement of the hemivertebra with narrowing of the vertebral canal

Fig 52 Lateral radiograph of the spine of a man, age 45 Wedge-shaped dorsal hemivertebra displaced posteriorly Marked gibbus deformity Large osteophytes in anterior margins of L 1 and L 3 which are in contact

The factors which are concerned in the production of a dorsal hemivertebra may, in theory, produce a ventral hemivertebra (fig 42, IV D) There is in the literature, however, only a single case of ventral hemivertebra, a case studied anatomically in the Institute at Dresden (figs 53 and 54) On sagittal section of the spine fibrocartilaginous tissue (the vestigial remnants of the notochord ?) is readily recognized This tissue occupies the posterior third of the vertebral body, and with the superadjacent and subadjacent discs, takes the shape of a horseshoe The radiograph (fig 54), which would be difficult to interpret without the anatomic specimen, shows the anterior half of the vertebral body to be fused laterally with the pedicles Contrary to the findings observed in dorsal hemivertebra, the ventral hemivertebra just described was of normal height and produced no deviation of the spinal column

Diethelm's "partial sagittal cleavage" of a vertebral body appears to be complementary to the case cited above with the sagittal cleft involving only the posterior part of the vertebra It is thus that he interprets our case reproduced in figures 53 and 54 with films of his own cases and with numerous citations A partial sagittal cleft involving the ventral portion of a vertebral body has been described by Hinze

Fig 53 (left) Photograph of a sagittal section of the thoracic spine of a woman, age 26 "Horseshoe" appearance of the discs above and below the ventral hemivertebra (T 10) Fusion of discs

Fig 54 (right) Radiograph of the same specimen

7. Vertebral cleavage in the frontal plane

Although, in an early developmental stage, the vertebral body is separated in its sagittal plane by a perichordal septum (fig 42, I), no such division is demonstrable anatomically in the frontal plane In the newborn infant, however, in a few rare instances, cleavage of a few vertebral bodies has been observed to occur in the frontal plane, dividing these vertebral bodies into ventral and dorsal halves (fig 42, V) Lossen has observed this phenomenon in a series of radiographs (fig 55) and Meyer-Burgdorff and Klose-Gerlich have made similar observations Histologic study showed the cleft to be filled with cartilage containing zones of growth, while only the central portions contained remnants of the notochord. Knutsson has observed, radiographically, frontal clefts in several thoracic and lumbar vertebrae in three newborn infants and has noted the disappearance of the clefts in from two to four months It is likely that these findings represent only a delay in the normal process of development (fig 42, V)

The extensive radiologic and anatomic investigations of Schinz and Tondury demonstrate that the appearance of ossification is dependent on vascularization, and that it begins in two centers, one dorsal and one ventral, each having its own medullary cavity with primary bone trabeculae Since the two foci fuse very early, most investigators seem to accept only a single ossification center Our earlier observations indicate that fusion is not always an early phenomenon, but may be somewhat delayed, and we remain of the opinion that primary ossification begins from two centers, one ventral and one dorsal, as illustrated in figure 42 (see also Fortschr Roentgenstr *68* 70, 1943) This concept adds greatly to our ability to explain the various anomalies

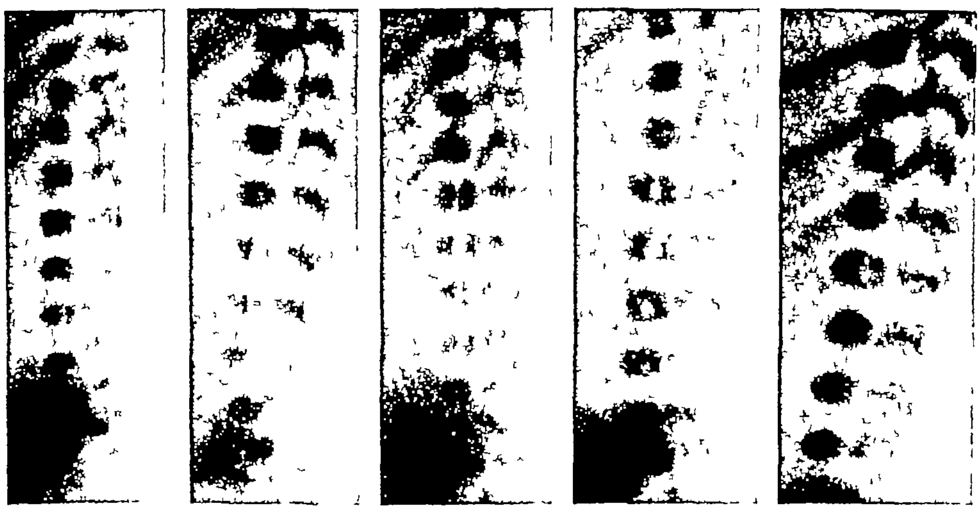


Fig 55 Lateral radiograph of the lumbar spine Fetuses of various lengths (A) 20 cm (B) 25 cm (C) 30 cm (D) 32 cm (E) 36 cm Frontal clefts of the vertebral bodies, varying in number and extent (Series of Lossen)

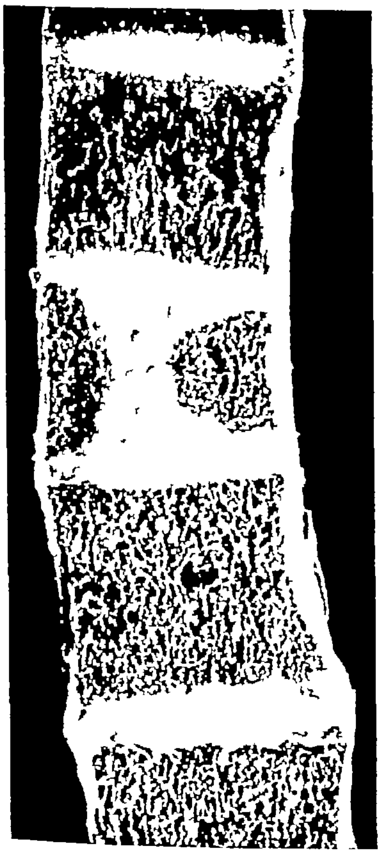
F W Rathke postulates the possible existence of a separating perichondral septum in the frontal plane and believes that frontal plane cleavage of a vertebral body may occur, occasionally, in adults Thus there exists the possibility of the division of a vertebral body into four quadrants

Diethelm, after consideration of the embryology and the radiologic evidence reaches a conclusion identical with ours He recognizes that the division of the vertebral body into a ventral and dorsal half may occur as early as the cartilaginous stage These ventral and dorsal half-vertebrae are independent during the segmentation process and either may become part of an adjacent vertebra, as indicated by Harrenstein's case The hypothesis advanced by Diethelm of the possibility of diagonal fragmentation of a vertebral body (and the consequent formation of vertebral quadrants) requires confirmation by anatomic and histologic studies

8. Anomalies of the notochord and the intervertebral discs

The functional relationship of the vertebral bodies and the discs is so intimate that a congenital anomaly of one will involve some variation of the other, and it is difficult, frequently, to determine which of the two elements was first involved This unity is made even more striking by the notochord which, in the early developmental stage, traverses the body-disc series in a craniocaudal direction Eventually it undergoes complete regression in the vertebral bodies, persisting only as the nucleus pulposus of the intervertebral disc (fig 43, p 25)

The regression of the notochord may be subject to arrest at any point in the developmental period, an arrest which may be recognizable in the completely formeds pine An otherwise normal vertebral body may exhibit, in its central portion, a cylindric canal containing a fibrous band which connects two adjacent discs (figs 56 and 57), recalling the conditions existing in the precar-



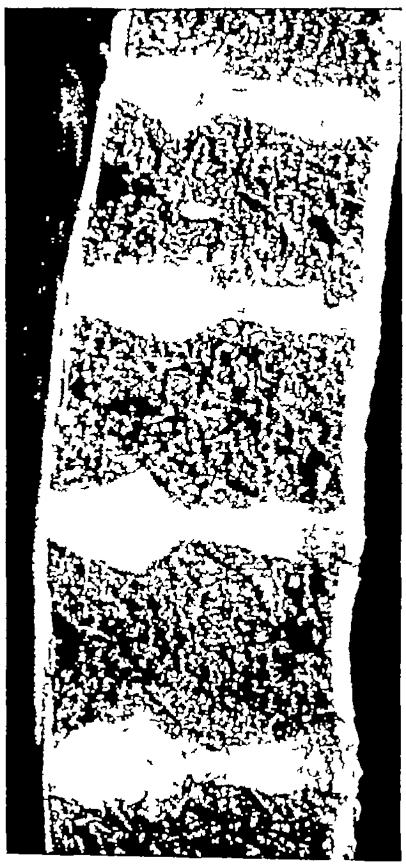


Fig 56 (left) Photograph of a sagittal section of the thoracic spine of a man, age 22 The discs above and below T 9 join by extending through the "persistent notochord canal"

Fig 57 (center) Radiograph of specimen in fig 56 Depression of vertebral plates (T 9) with wedging

Fig 58 (right) Photograph of the sagittal section of the thoracic spine Man, age 38 Biconcave expansion of the discs in the region of the nucleus pulposus

tilaginous phase Such a "persistent notochord" (fig 42, II B) has been observed very rarely (Musgrove, Schmorl) In the disc area, the canal may widen to assume a funnel shape and this may interfere with normal vertebral growth This feature has been described above as forming part of the sagittal cleft vertebra (figs 47 and 48)

Small inclusions of the notochord may be encountered in various parts of the vertebral body where they are seen as small islands of pale, gelatinous tissue surrounded by cartilage Schmorl noted them frequently in microscopic sections and they must be considered as remnants of the notochord which have not undergone complete regression and should not be confused with fragments of the annulus or the nucleus which have been displaced into the cancellous bone or the paravertebral area (Schmorl's nodes, pp 133 and 141)

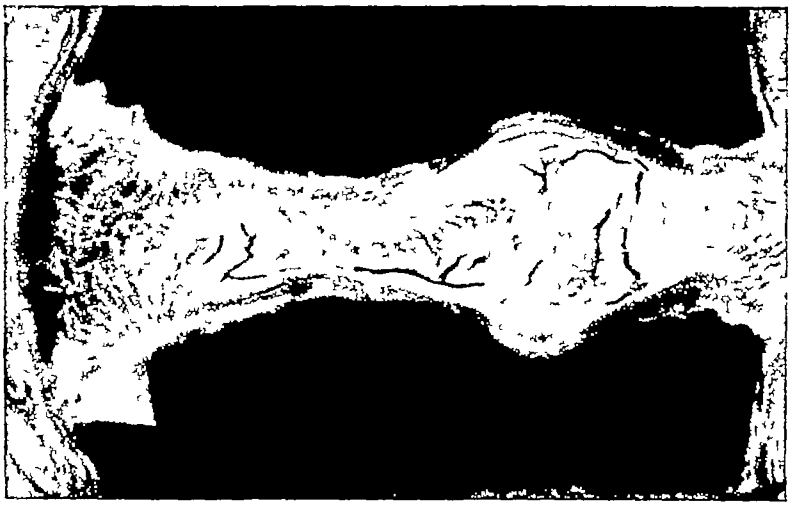


Fig 59 Photograph of the sagittal section of the disc and the adjacent vertebral plates of a child Disc expansion in region of nucleus pulposus Thin, but intact, cartilaginous plates (cf fig 368ff) The vertebral rim (still cartilaginous) extends into the vertebral body (cf fig 7)

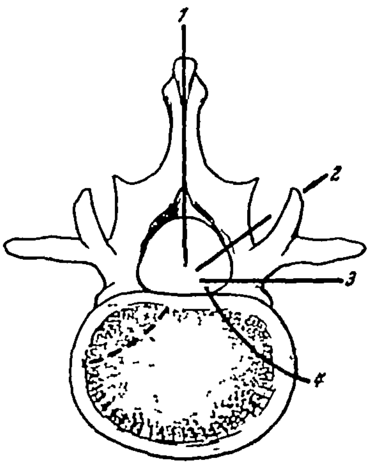


Fig 60 (left) Lateral radiograph of the spine of a girl, age 15 Expansion of the discs in the region of the nucleus pulposus (see fig 58) (The site of the passage of the notochord in the embryonal stage)

Fig 61 (right) Drawing of a lumbar vertebra, seen from above (1) cleft spinous process (2) cleft pars interarticularis (3) cleft in the pedicle (4) junction of the pedicle and vertebral body (neurocentral junction)

In the course of the regression of the notochord there may appear certain other disc anomalies of considerable clinical importance These are the so-called "localized expansions of the discs" in the region of the nucleus pulposus, where there are funnel-shaped extensions into the vertebral plates They may be seen in one or several discs, especially in the lower thoracic region (fig 58), and their location corresponds to areas of incomplete obliteration of the notochord, remnants of which constitute the nucleus pulposus The topographic relation of the nucleus and these vertebral plate depressions is of considerable significance in the pathology of this region and will be discussed later (Chapter VI A2, figs 368 – 370) The thinning of the vertebral plate adjacent to the expansion of the disc produces an area of decreased tensile strength (fig 59) Further study is needed for evaluation of Buchner's theory of damage resulting from hypoxemia during the embryonic stage of development (Chapter I C, II A 1 and A 8, IV C 1)

Disc expansions (or depressions of the vertebral plates) in the area of the nucleus pulposus are readily shown radiographically (fig 60) They are not rare, and one must look for them, especially, when examining the spines of young persons in whom these changes predispose to such entities as Schmorl's nodes and juvenile kyphosis Such patients should be restrained from activities which impose excessive stresses on the spine (strenuous sports, hard labor, motorcycle riding, etc)

B. Congenital anomalies of the vertebral arch

As the notochord plays a dominant role in the development of anomalies of the body-disc series, the neural tube is a determining factor in the formation of the anomalies of the posterior arch The relation of anomalies of the neural tube and those of the arches has been investigated extensively by Recklinghausen, Klebs, Mathis, Feller and Sternberg and others Posterior cleavage of the vertebral arch may be associated with various anomalies involving the meninges and the cord, myelocele, meningocele, myelomeningocele, myelocystocele, myelocystomeningocele, etc F A Hesse has prepared a bibliography and detailed review of the etiology and the classification of these anomalies

The existence of a cleft is the commonest anomaly of the vertebral arch and is much more common than a cleft of the vertebral body (fig 61) The presence of multiple clefts is of considerable clinical importance since they give rise not only to serious complications including cord and nerve lesions, but to deformities of the spine resulting from disturbed static relations Narrow linear clefts, and those at the level of the spinous processes have no clinical significance The usual radiographic projections do not always demonstrate clefts of the vertebral arches and oblique projections are frequently necessary Differentiation between a fracture and a congenital cleft may be quite difficult

1. Cleavage of the spinous process

The spinous process, entirely cartilaginous at birth, is formed by the fusion of the two halves of the vertebral arch In the first year of life ossification occurs from two centers and, if it fails to extend into the spinous process, the resulting cleft remains filled with cartilage (posterior spina bifida) (line 1, fig 61) This anomaly is of frequent occurrence, and may involve one or several processes It is most common in the area of the transition of one spinal region into another (fig 62)

The cleft is usually quite readily recognizable in a radiograph It may happen, however, that the development of the two halves of the arch is not equal and in this case the cleft may not be placed in the midline and, hence, may be difficult to recognize radiographically We do not agree with Willis, who considers this sort of laterally located cleft as a separate anomaly It should be noted that the two halves of the spinous process are sometimes displaced, one overriding the other, an occurrence easily recognized in a roentgenogram (figs 63, 64 and diagram by Köhler) The horizontal cleavage of the spinous processes described by Heeren probably represent such overriding The cleavage of the spinous processes varies considerably in the several regions of the spine According to Hintze, in a right-handed person, the tip of the left half of the process will be above the right

Fig 62 Radiograph of the thoracolumbar region of a young adult Cleft spinous processes of T 11, T 12, and L 1

Cleavage of the spinous processes in the cervical region has been described frequently (Askey and Collins, Le Double, Gruber, W Muller, Schinz, and others) It involves, commonly, the atlas and is seen only rarely in the lower cervical area With systematic radiographic examination Geipel found in 3 per cent of his cases a cleft in the posterior arch of the atlas He has offered a detailed description of this anomaly, including forty-four personal observations In his monograph on the atlas, Dubreuil-Chambardel gave a thorough description of this anomaly and Arkussy, Disse, Feci, Fick, Frei, Hyrtl, Kohler, Reisner, Renander, and others have reported isolated cases The frequency of cleavage of the arch of the atlas may be due to the fact that normally it ossifies rather late, i e, in the fourth or fifth year of life A posterior cleft may occur in the axis and, rarely, such a cleft may occur anteriorly

in the atlas (Geipel, Engländer, Teichert) This anomaly is, however, of different origin since the anterior arch of the atlas does not follow the same developmental process as does the body and arch of the axis

The thoracic vertebrae only rarely exhibit cleavage of the vertebral arches and, when such cleavage does occur it is usually at one pole or the other of the thoracic spine The lower portion of the thoracic spine is most commonly involved, but W Müller and Schuppler have observed it in the first thoracic vertebra, and Torbin and Jahn have described it in the third and fourth thoracic segments The most common involvement is in the lower thoracic and upper lumbar areas (fig 62)

A fairly wide cleft may be present in the arch of a lower lumbar or sacral segment, and the relation of this anomaly to lowback pain has been discussed extensively in the literature The spinous processes of the lumbosacral segments, uniformly open during the first postnatal years, tend to close at from 4 to 6 years of age Eighty-one per cent remain open at 5 years of age, 44 per cent at 15, and, even at 50, 10 per cent of them are still unfused (Hintze) Meyer found cleft arches to be present in 24 per cent of persons more than 24 years of age, while Heise observed this anomaly in 22 per cent and Grässner in 16 per cent of persons of that age In Neubert's series it was present in 23 per cent of men and 14 per cent of women Lubke found clefts in the sacral arches in 24 per cent of subjects examined and Willis considers a cleft in the arch of S 1 to be of such regular occurrence as to constitute a normal finding It was present in L 5 in 1 2 per cent of his cases (Lubke's series 1 5 per cent, Brailsford's series 6 per cent) Cleavage of the entire series of sacral arches was seen by Lübke in 1 5 per cent of cases, by H Mayer in 4 per cent, by von Beck in 3 per cent, by von Adolph in 3 per cent, and in about 8 per cent by von Ryzov (9 instances in 116 spines)

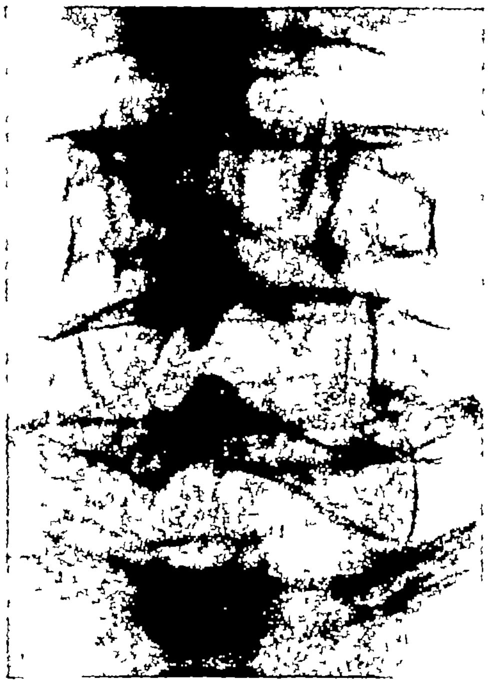


Fig 63 (left) Photograph of the posterior aspect of a macerated lumbosacral spine Man, age 64 Cleavage of the spinous process of S 1 with halves of arch overriding

Fig 64 (right) Anteroposterior radiograph of the lumbosacral region of a man, age 80 Cleft in the arch of L 5 with slight overriding of the two halves

Cleft arch is a common anomaly of the lumbosacral segments and, generally, is of little clinical significance Hintze has suggested "lumbosacral fontanel" as a substitute for "spina bifida" or "spina bifida occulta "

True spina bifida and spina bifida occulta, in which the anomalies of the vertebral arches are associated with neurologic findings, will not be discussed at this time Hypertrichosis of the sacral area, areas of hyperpigmentation, scarring and areas of visible or palpable swelling arouse the suspicion of neurologic disturbances associated with cleavage of the vertebral arches (von Recklinghausen, 1886) Enuresis, clubfoot and various neurotrophic disorders suggest the presence of spina bifida The symptoms of spina bifida may be observed without any demonstrable changes in the vertebral arch (spina bifida occulta) and radiographic findings do not constitute the decisive factors in the diagnosis Bibliography Ask, Curtius, Estor, de Fayay, Jirasek, Kunze, Lagrot and Cohen-Sola, Lehmann, Leveuf, Mertz, Obstaender, Schroder and Hillenbrand et al

Not uncommonly solitary cysts of the sacrum are observed involving both the body and the arch (figs 65 and 66) These are known as "spina bifida incompleta" and Kleiner studied 48 such cases in the Dresden Institute They do not, usually, communicate with the spinal canal, and appear to consist of isolated spaces with a lining of dura and filled with cerebrospinal fluid Occasionally, they are traversed by nerve fibers (Kleiner, Barsony and Winkler)

2. Nonfusion of the pars interarticularis (spondylolysis, spondylolisthesis)

Although spina bifida is of little clinical importance, nonfusion of the lateral aspect of the vertebral arch (which occurs most often in the lower lumbar spine) is of considerable significance (fig 61) It may occur on either side in the interarticular portion of the arch, i e , between the superior and

inferior articular processes (fig 67) Thus, it divides each half of the vertebral arch into two segments, the anterosuperior portion, which consists of the pedicle, the superior articular process and the transverse process, and the posteroinferior portion which has the inferior articular process, the posterior portion of the lamina of the arch and the spinous process Since the process, called spondylolysis,

Fig 65 (left) Photograph of a sagittal section of the lumbosacral spine of a man, age 68 Smooth-walled cyst of S 1, protruding into the neural canal

Fig 66 (right) Lateral radiograph of a sagittal section of the lumbosacral spine of a woman, age 78 Cyst of S 2 and S 3 protruding into neural canal

is responsible for the vertebral gliding of spondylolisthesis, this dysplasia is of great clinical significance as is reflected in the extensive literature Whether the defect is of congenital or acquired origin is very controversial Normally, there is only one ossification center for each half of the vertebral arch and, probably, there is only one cartilaginous portion for each half Many writers believe, however, that, in the early embryonal stage, each half of the arch consists of two fragments, one anterior and one posterior According to Putti, this arrangement is a normal feature in the cetacea, but, in man, represents a regressive anomaly Poirier and Charpie, Keibel and Mall, Farabeuf, Bardeen, Schwegel, and others have cited instances of the presence of two ossification centers in each half of the vertebral arch and Willis has confirmed these observations by histologic studies Spondylolysis has been observed in children (Brailsford, Capener, Eichlam, Garavano, George and Leonard, Guellemmet, Hitchcock, Jenkins, Johnstone and Thompson, Junghanns, Kleinberg,

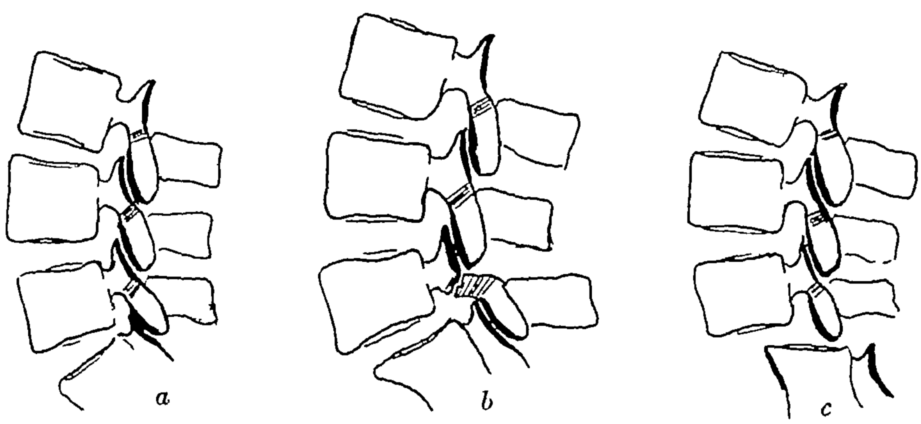


Fig 67

Tracings of lateral radiographs of the lumbosacral junction (A) normal lumbosacral region (B) true spondylolisthesis (L 5) with cleft in the pars interarticularis of L 5 (C) dislocation of L 5 The inferior articular process of L 5 rests on the sacrum Intact pars interarticularis

Fig 68

Fig 69

Fig 70

Fig 68 Lateral radiograph of a sagittal section of the lumbar spine Male, age 22 Cleft in the pars interarticularis of L 5 (spondylolysis) without spondylolisthesis

Fig 69 Lateral radiograph of the lumbosacral region of a man, age 23 Bilateral clefts of the pars interarticularis of L 5

Fig 70 Lateral radiograph of a sagittal section of the lumbar spine Man, age 60 Moderate spondylolisthesis of L 3 Cleft in the pars interarticularis of L 3 (arrow). Narrowing of disc space of L 3—L 4 Anterior and posterior osteophytes

Kuttner, Langendorf, Meyerding, Mosberg, Priessnitz, Reisner, Rocher and Roudil, Röderer and Cherigie, Schmorl, Silverskiöld, Taillard, Weil et al), and Schmorl has carried out histologic studies of spondylolysis in a 2 year old child Friberg studied 280 cases of spondylolisthesis and found 37 cases in patients less than 20 years of age, and 3 cases in children less than 10 Barrand has reported a case of a infant of 10 months with spondylolysis of all of the lumbar vertebral arches

Many years ago Neugebauer expressed the opinion (now supported by clinical and embryologic studies by numerous investigators) that spondylolysis is of congenital and developmental origin (Abraham, Belot and Nadal, Benassi, Congdon, Faldini, Friedl, Garavano, Gaugele, George and Leonhard, Hellner, Huber, Hartung, Janssen,

Fig 71 (left) Photograph of the sagittal section of the lumbosacral spine Woman, age 59 Spondylolisthesis (1 2 cm) of L 5 Cleft of the pars interarticularis of L 5 with osteophyte formation Marked narrowing of the L 5—S 1 interspace Osteophytes bridging the anterior margins of the disc spaces

Fig 72 (right) Photograph of the macerated specimen shown in figure 71

Joisten, Junghanns, Kleinberg, Kopits, Mercer, Mouchet and Roederer, W Muller, Pavlik, Reisner, Rocher and Roudil, Roederer and Glorieux, Schmarjewitzsch, Schmorl, Schuller, Schaer, Stewart, Streinart, zur Verth, Wegener, Weil, Wette, Willis, Warner, Wunderlich et al) Turner and co-workers consider intra-uterine trauma to be responsible for spondylolysis Others, however, believe that a defect in the pars interarticularis is invariably of postnatal traumatic origin and that, in a few exceptional cases, a symmetric bilateral fracture results in spondylolisthesis (Bohler, Hitchcock, Holfelder, Reisner, Ryzor, Mjakovitsch, George, Leonard, Mandler et al) Thus far, experimentally, no one has demonstrated the production of a symmetric bilateral fracture of the interarticular portion of the arch without prior damage to this segment (Turner and Markallow) Lane, Mouchet and Roederer, Turner and others have held that it was possible for shearing forces to produce, at the level of the articular processes of L 4 and S 1, a gradual traumatic dehiscence of the pars interarticularis of L 5 This opinion is supported by Meyer-Burgdorff who considers spondylolysis as a final stage in the post-traumatic osteogenic process (umbauzones) Brocher thinks that spondylolysis occurs, during the postnatal period, in a vertebral arch exhibiting dysplasia and, to support his view, points out that dysplasia of the vertebral arches is of quite common occurrence (see p 123) Brauer believes that the spondylolysis frequently seen in contortionists represents fatigue fractures The histologic studies of Schiedt (Institute of Tondury) indicate that the ossification of the vertebral arches is perichondral, rather than enchondral (see Chapter I B), and that it is unlikely that the appearance of two abnormal ossification centers would result in the formation of a cleft in the pars interarticularis and, if there is a congenital cleft, it must have developed during the preossification stage The clinical and radiologic literature on this subject is not only extensive but controversial, and we shall not attempt a complete bibliography (Burckhardt, Colonna, Gajzago,

Grashey, Hammerbeck, Iles, Jonkhere and Leclerq, Junghanns, Kowacs, Liechti, Mathieu and Demirleau, Meyer-Burgdorff, W Müller, Newmann, Orth, Rathcke, Reinbold, Regensburger, Reischauer, Roche, Ruhnau, Schanz, Sisefsky, Tondury, Wallgren, Wolff et al)

Our personal investigations, carried out in the Dresden Institute, lead us to believe that the defect in the pars interarticularis of the arch (spondylolysis), responsible for the occurrence of true spondylolisthesis, is a congenital anomaly Favoring this hypothesis (aside from the facts of embryology) are such findings as the occurrence of the anomaly in children and adolescents, heredity (Friberg, Harbitz), its frequent relation to other congenital anomalies, and the irregularity of the opposing margins of the cleft, which closely resemble epiphyses in other locations This theory is also supported by the presence of a cleft in the spinous process of the same vertebral segment frequently observed in our cases (Charry, Dieszl, Michaelis, Pannhorst, Rocher and Roudil, Willis) The fact that Willis found spondylolysis to occur twice as often in spines with a numerical anomaly of the vertebrae as in spines with a normal numerical arrangement, favors the congenital origin of spondylolysis Willis also frequently observed vascular channels at the site of the defect

Fig 73 Photograph of the sagittal section of the lumbosacral spine Man, 61 Spondylolisthesis of L 5 (0 5 cm) Cleft in pars interarticularis of L 5 Osteophyte formation on anterior vertebral margins and shelf-like bone formation on the superior anterior margin of S 1

In the literature, there is considerable divergence of opinion as to the frequency of the occurrence of spondylolysis Neugebauer estimated that 5 per cent of spines exhibit a defect in the pars interarticularis and although this number was long considered as rather large, its correctness has been confirmed in recent publications Willis has reported the mean frequency of spondylolysis to be 5 19 per cent, the variants being white males 6 6 per cent, negro males 3 5 per cent, white females 3 7 per cent, and negro females 1 03 per cent Quite marked racial differences were observed by Stewart who found this anomaly in 6 4 per cent of white Americans, and in 2 8 per cent of negro Americans It was present, however, in 8 9 per cent of Bantu negroes and in 27 4 per cent of Eskimos In view of these rather large percentages it is surprising that Roederer and Glorieux found a cleft in the pars interarticularis in only 2 per cent of their cases Congdon found bilateral spondylolysis in 5 per cent of 200 spines examined The most common site of spondylolysis is L 5, and 66 6 per cent of all of these lesions occur at this level L 4 is second in frequency of occurrence with from 15 to 30 per cent Spondylolysis occurring in other vertebral arches includes L 3 (Abraham, Burckhardt, Le Double, Junghanns, Lane, Malkin, Meyer-Burgdorff, Meyerding, W Muller, Neugebauer, Treub, Willis), L 2 (Reischauer), L 1 (Broca), L 6 (Willis, 6 cases), S 1 (Sandifort), and Neugebauer has observed this anomaly in the cervical and thoracic vertebrae Liechti has presented a case of bilateral spondylolysis at C 4, occurring in a gorilla Multiple defects in the vertebral arches have been reported, involvement of L 4 and L 5 (Abraham, Congdon, Grashey, Harbitz, Junghanns, Willis and others), L 2 and L 5 (Reischauer) Stewart found spondylolysis of two vertebral arches in 20 cases, and of three arches in 2 cases The defect is commonly bilateral In the rare instances of unilateral defect, the lesion is usually right-sided (Willis) and results in rotation of the vertebrae (Glorieux)

The incidence of the occurrence of this anomaly seems to be the same in both sexes and the earlier opinion that it was more common in females appears to be incorrect (see table 1) The error lay in assuming the obstetric importance of the defects which, today, are of equal importance to the surgeon, the orthopedist and the radiologist

Cleavage of the pars interarticularis is recognized readily in a macerated specimen but is demonstrated radiographically usually in films made in the oblique projection In spondylolisthesis, the lateral projection permits demonstration of the anteriorly displaced vertebra In exaggerated cases, the entire spine above the level of the displacement may have moved forward even into the pelvis Usually, the displacement which is best measured along the posterior vertebral margins (Junghanns)

is of moderate degree Cleavage of the pars interarticularis, essential to the production of true spondylolisthesis, is located, invariably, behind the inferior border of the superior articular facet, thus dividing the pars into a smaller superior and a larger inferior segment (figs 68—79) Histologic examination shows the presence of bundles of fibrocartilaginous tissue which, with Sharpey's fibers, are inserted deeply into the osseous structure It should be remembered that although the defect or hiatus of the pars interarticularis has the appearance of a slit, radiographically, it is an actual hiatus, filled with well differentiated tissue The stresses of everyday life may lead to fissuring and to vascular invasion of the tissues filling the hiatus Areas of calcification, osseous inclusions and fragments of degenerated tissue may be seen on microscopic examination, but there is a dearth of such studies available (Hammerbeck, Junghanns, Meyer-Burgdorff, Schmorl, Willis)

Table 1

Cases of Spondylolisthesis and Pseudospondylolisthesis Examined Anatomically in the Dresden Institute

1	2	3	4	5	6
		5	4	3	
Diagnosis	Sex	Lumbar vertebra			Total
True spondylolisthesis	Men	14	6	1	21
	Women	16	9	—	25
	Total	30	15	1	46
Pseudospondylolisthesis	Men	—	2	1	3
	Women	2	7	2	11
	Total	2	9	3	14
	Totals	32	24	4	60

The hiatus varies in width, but is usually of the magnitude of the anterior displacement of the vertebra However, it may be minimal, even though there is quite marked vertebral displacement This is because of the elongation of the posterior segment of the interarticular portion of the lamina (figs 75 and 76) Not uncommonly, in the aged, fragmentation and degenerative changes of the fibrous tissue result in abnormal mobility with subsequent formation of osteophytes bridging the hiatus (fig 75) Occasionally, ossification of the hiatus occurs (fig 74), preventing the vertebral displacement Extensive destruction of fibrous tissue may result in such displacement of the fragments of the isthmus and their loss of contact that they cease to face each other (fig 79) Following spondylolisthesis spinal lesions may develop, and these will be mentioned briefly They involve particularly the "motor segment" (p 21) For the entire life of the individual, the presence of the hiatus reflects lessened resistance to the stresses of life, and even slight motion at this level may lead to fissuring of the

Fig 74 Lateral radiograph of a sagittal section of the lumbosacral spine Male, 68 Spondylolisthesis of L 5, slight narrowing of disc space L 5—S 1 Fusiform thickening and irregular trabecular pattern and cleft in pars interarticularis of L 5 (arrow) Bony bridging of the cleft

annulus fibrosus and to steadily increasing fissuring and degeneration of the entire intervertebral disc A disc which has undergone pathologic changes is less elastic than a normal disc and has less resistance to stress These changes tend to damage the fibers of the hiatus and thus there is initiated a vicious circle with increasing anterior displacement of the vertebral body leading in turn to further damage to the fibers of the hiatus With increasing destruction of

Fig 75 (left) Lateral radiograph of a sagittal section of the lumbosacral spine Male, 84 Spondylolisthesis of L 5 with marked narrowing of L 5—S 1 disc space and "shelf-like" formation on the anterosuperior margin of S 1 Cleft in pars interarticularis of L 5 with a large osteophyte Osteoporosis

Fig 76 (right) Lateral radiograph of a sagittal section of the lumbosacral spine Male, 57 Spondylolisthesis (0 8 cm displacement) of L 5 Cleft in the pars articularis (arrow) Narrowing of disc space L 5—S 1 and osteophyte on S 1

the disc and consequent loss of height and elasticity, eburnation of the opposing vertebral plates occurs (figs 71, 72, 77) and there appears the characteristic "shelf formation" on the anterosuperior margin of the vertebra below This is recognized readily in figures 71, 73, 75 and 77, where there are also bridging osteophytes with anterior reinforcement of the sacral promontory, This feature represents, probably, an attempt at containment of the forward slipping vertebra Moreover, ossification of the intervertebral disc may occur (Schmorl) Meyer-Burgdorff and Sandmann have investigated the relationship between these disc changes and spondylolisthesis Sillevis-Smith has noted that marked spondylolisthesis may result in compression of nerve roots with subsequent neurologic symptoms

As is true in all congenital anomalies, trauma may be a factor which aggravates spondylolysis and spondylolisthesis, and it is very difficult to determine to what extent trauma is responsible (Nontraumatic spondylolisthesis, lesions other than congenital defects of the interarticular portion of the vertebral arch, and so called "pseudospondylolisthesis" will be discussed in Chapter VIII A and B)

In general the treatment of spondylolisthesis is conservative although there have been devised several surgical procedures for immobilization of the involved area (Adkins, Baumann, Bosworth, Burns, Colonna, Dandy, Denecke, Erlacher, Francillon, Gill with Manning and White, Hauberg and Schlüter, Henschen, Ingebrigtsen, Junge and Kühl, M Lange, Neff, Ponzoni, Ramser, Rathcke, Salmon and Contiades, Schüller, Taillard, Wyss, Yoshimine et al With marked vertebral displacement and with symptoms arising from nerve root compression, posterior surgical immobilization and freeing of the nerve roots may become necessary

Fig 77

3. Cleft pedicle

Hammerbeck has reported 2 cases in which he observed a vertical cleft in the vertebral pedicle In one of these, the cleft was bilateral and involved L 4 In the other, there was a cleft in the right pedicle of L 3 and another in the interarticular portion of the arch on the left side, associated with bilateral spondylolysis and spondylolisthesis of L 4 This bilateral cleavage resulted, in the first case, in slight anterior displacement of the vertebral body and arch Since the vertebral column above was not displaced anteriorly (as in true spondylolisthesis) the case could not be considered one of spondylolisthesis On histologic study Hammerbeck

Fig 78

Fig 77 Lateral radiograph of a sagittal section of the lumbosacral spine Woman, 60 True spondylolisthesis of L 5 with cleft in pars interarticularis Narrowing of disc space L 5—S 1 and shelf-like formation on anterior margin of S 1

Fig 78 Lateral radiograph of a lumbosacral spine Woman, 56 Spondylolisthesis of L 5 with slight narrowing of the disc space L 5—S 1 Wide cleft in the pars interarticularis containing a few bone spicules Small osteophyte on the anterosuperior margin of the sacrum

found a true synchondrosis of the pedicles, and this is believed to have resulted from the presence of two ossification centers or the division of one ossification center in the embryonal period He rejected the theory of "umbauzones"

A cleft in the pedicle of L 2 was observed radiographically by Assen, who considered that it represented persistence of the so-called "epiphysis of the vertebral arch" (see p ff), an opinion which does not seem convincing to us Additional study seems to be needed

Fig 79 Lateral radiograph of the lumbosacral spine Man, 68 True spondylolisthesis of L 4 The metallic clips indicate the separated surfaces of the dehiscent interarticular portion Marked narrowing of the disc L 4—L 5 and sclerosis of the adjacent vertebral plates

4. Cleavage at the junction of the vertebral body and the vertebral arch

The cartilage interposed between the vertebral body and its arch ("intervening cartilage") persists from the third to the sixth year of life, when fusion of these two segments is complete To a considerable degree the pedicle contributes to the formation of the vertebral body (figs 10 and 61), and one would expect to find a cleft in this region if fusion did not occur (Rathke) In the schema of Willis he indicates a possible cleft in this portion of the vertebra, but his material contains no example of its occurrence In the large collection of spines in Schmorl's Institute we were unable to find an example of a cleft at this point in any of the macerated spines of adults

Meyer-Burgdorff and Klose-Gerlich have described a unilateral cleft at the junction of the vertebral body and the arch in each of two newborn infants Although such clefts must be very rare, one may observe, frequently, small vestigial remnants of cartilage in these areas, occasionally surrounded entirely by cancellous bone These vestiges are seen commonly connected with the cartilaginous plate of the vertebra and extend somewhat into the vertebral body

5. Partial or complete agenesis of the vertebral arch

After ossification has been completed one may observe the absence of half, or even all, of a vertebral arch or the arch may be more or less distorted (Diesse, Geipel, W Muller, F M Rathke, Walter) Whether the anomaly *is partial or complete, isolated or associated with analagous anomalies* of the vertebral bodies, it is not always possible to determine whether they represent agenesis of embryologic origin, arrest of development of cartilage, or disturbance in the process of osteogenesis Careful histologic studies are badly needed (see Schema of Putti) The radiographic recognition of the anomalies of the vertebral arches is beset with difficulties and special projections must be made to eliminate the numerous possible superimpositions of bony structures Planigraphy may be very helpful

6. Congenital synostosis of the vertebral arches

In the discussion of "block vertebra" we have mentioned the possibility of congenital synostosis of the arches (fig 45) Thus far, we do not know whether the synostosis begins in the body-disc series or in the vertebral arches Klippel-Feil's syndrome, in which the important finding is the fusion of a number of the vertebral arches, will be discussed later (see p 58). Hemimetameric displacement

frequently results in varying fusions of the vertebral arches thus creating various body-arch anomalies One half of a displaced segment may fuse with a nondisplaced segment with a resulting malformation It is not known whether the two halves of the vertebral arch are independent during the rearrangement process The corresponding transverse processes may, or may not, participate in the fusion (Calalco), and this may be recognizable radiographically

7. Congenital anomalies of the articular processes

The orientation of the surfaces of the articular processes varies with the spinal segment under consideration and on the type of motion which occurs at any given level of the spine (Braus, Fick, Kuhns, M Lange, Strasser, Stieve) The change in the orientation of these surfaces is a subtle and progressive deviation of the axes of the articular facets In the thoracic spine the articular surfaces are in the frontal plane, but because of their progressive deviation they are oriented in the sagittal plane in the lumbar spine This arrangement may be modified by congenital variations and, in any vertebra, the small joints may be asymmetric with one pair facing each other in the anteroposterior position while the opposite pair face laterally (Gold-Sweit, Junghanns, V Lackum, Schertlein) These variations have been studied extensively in the lumbosacral region (fig 219), but their relationship to back pain or to interference with mobility is not known The radiographic demonstration of asymmetric articular facets does not necessarily indicate the presence of a pathologic process

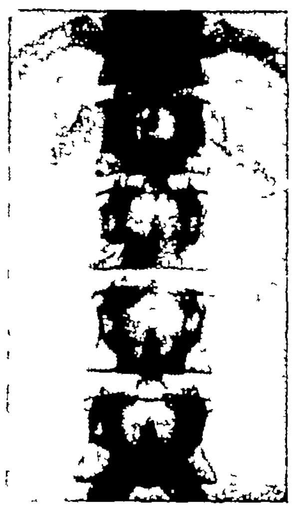


Fig 80 (left) Radiograph of the lumbar spine of a young man Absence of the spinous process of L 1 (white arrow)

Fig 81 (right) Radiograph of the lumbar spine of a middle-aged man Osseous bridging of the right transverse processes of L 3—L 4

Aplasia of one or both articular processes of a given vertebra is very rare W Müller has observed, radiographically, absence of both inferior articular processes of L 2 and Lassen has described partial aplasia of an articular process of L 5 Absence of the superior articular processes has not been reported

Cleavage of the spinous process has been described earlier (p 35) A spinous process may be subject to developmental arrest as may an articular process, and may exist only as a rudimentary tubercle (fig 80) Such hypoplastic spinous processes and those that are placed obliquely (easily recognizable by clinical and radiologic studies) may give rise to functional disturbances produced by defective muscle insertion and resulting abnormal stresses (Barsony and Winkler, Irsigler, Tavernier, Schlutzen)

An acessory tubercle on the posterior surface of a transverse process may exhibit congenital hypertrophy producing a so-called styloid process Although these accessory tubercles are rarely more than 3 to 5 mm in length, about 7 per cent of lumbar spines present styloid processes more than 1 5 cm long occurring bilaterally on several vertebrae (Meyer-Burgdorff) Familiarity with the existence of these styloids is of importance in the interpretation of a radiograph (Rubaschewa, Volkmann and others)

The mamillary process is a small bony protuberance located slightly lateral to the posterior margin of the facet of the articular process It develops from a separate ossification center which appears at puberty and which, at the end of the growth period, fuses with the superior articular process (Chapter I B, p 10) Abnormal hypertrophy of this process may occasion some difficulty in the interpretation of a radiograph (Anovazzi and Giraudi)

The transverse processes, especially at the level of the transition of one region of the spine to another, present a series of congenital malformations These are to be regarded as variants and will be discussed in Chapter II C Occasionally, one may encounter a hypertrophied transverse process

which resembles that of a transitional vertebra and which may articulate with an adjacent process of like nature (fig 81, Muzel, Rövekamp) Bony bridging between the transverse processes of the cervical vertebrae has been described by V Unteruchter, and Pickman has noted the presence of unusually large transverse processes of the second cervical vertebra

8. Nonfusion of the apophyses and the vertebral processes

The previously described secondary ossification centers of the apophyses of the vertebral arch (Chapter I B, p 10) may undergo developmental arrest (as demonstrated by Disse) and may be seen in a radiograph as small, independent bones These nonfused apophyses were observed frequently by Graberger They are especially frequent in the transverse processes of T 1 (0 7 per cent) and in the alae of the sacrum (Giraudi)

Fig 82 Anteroposterior radiograph of the lumbar spine of a middle-aged man Spina bifida of S 1 with small bony islet (the apophysis of the spinous process) in the cleft

Nonfused apophyses of the spinous processes are fairly common and according to Gazotti, may be a source of pain They may be mistaken for fractures A peculiar feature of the nonfused apophyses of the spinous processes is their development in the presence of a sagittal cleft When this occurs the apophysis appears as a bone island in the wide gap of the hiatus (figs 82—84) When there is an extensive hiatus of the sacrum the spinous apophyses may fuse and appear as a long, narrow bony strip along the hiatus (figs 85 and 86) We have seen a few cases of nonfused arches of the first sacral segment with a well developed spinous apophysis exhibiting firm union (connective tissue or bony) with the spinous process of L 5 With the enlarged and downward projecting spinous process of L 5, diagnostic difficulties may present themselves (fig 86, Goljantizki)

The nonfused apophyses of the articular processes (p 10) are of considerable interest because of their not infrequent misinterpretation as fractures It is unfortunate that, thus far, we have not

Fig 83 (left) Photograph of the posterior surface of the lumbosacral spine of an elderly man Macerated specimen Spina bifida of S 1 Apophysis of spinous process is seen as a bone islet in the cleft

Fig 84 (right) Radiograph of specimen shown in figure 83 The nonfused apophysis of spinous process is indicated by an arrow

careful anatomic or histologic studies of these anomalies Le Double considers them to be of extreme rarity Nonfused apophyses of the inferior articular processes have been observed frequently (Baake, Büscher, Fulton and Kalbfleisch, Grashey, Ivanov and Rotaermel, Kobayashi, Lang, de Marchi Reisner, Rendig, Westing, Nichols and Shiflett, W Muller, Giraudi, Litten, Nissler, Nöller, Regensburger et al) Farmer collected 40 cases which concerned, mainly, L 2 or L 3 (fig 88), and only 5 cases involved the superior articular processes It is debatable whether these

Fig 85 (left) Photograph of posterior surface of the lumbosacral spine Male, 82 Macerated specimen Complete sacral hiatus with a mid-line bar of bone formed by fused apophyses of the spinous processes Fusion of apophysis of the spinous process of S 1 with the spinous process of L 5

Fig 86 (upper right) Radiograph of the specimen shown in figure 85 Arrow indicates the apophysis of the spinous process of S 1 X—X indicates the osseous bar in the sacral hiatus

Fig 87 (lower right) Photograph of the posterior surface of a macerated specimen of the lumbosacral spine The hypertrophied spinous process of L 5 extends into the cleft of S 1 (spina bifida)

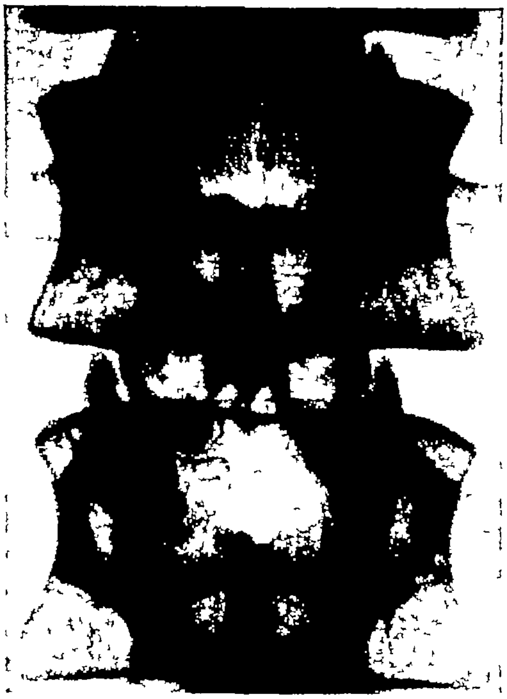


Fig 88 Anteroposterior radiograph of part of the lumbar spine Male, 31 The right inferior articular process of L 3 has an unfused apophysis

bony bodies represent normal apophyses which might be expected to fuse with the articular processes or whether they represent malformations which exhibit no tendency to fusion Buscher reminds us that calcification of the articular capsule must be borne in mind in differential diagnosis

C. Morphologic variations of the vertebral column

The numerical order of the vertebrae and the presence of "transitional vertebrae" in the vertebral column is of great importance to the radiologist, and these transitional forms are the source of many diagnostic difficulties Variations of the apophyses of the transverse processes of the thoracolumbar spine may be confused with fractures, renal and ureteral calculi, calcification of mesenteric nodes, etc The anatomists of the Middle Ages knew that the number of the vertebrae in the various regions of the spine might vary, as might the total number of the segments of the vertebral column Rosenberg has studied the numeration of the vertebral segments and has established the normal figure H Frey, Rosenberg and Paterson have agreed on a formula, applicable to 65 to 75 per cent of humans, in which the following distribution seems normal cervical spine 1 to 7, thoracic spine 8 to 19, lumbar spine 20 to 25, sacrum 26 to 29, and coccyx 30 to 33 About one third of all spines show numerical variations with an increase or decrease in the total number of the vertebrae, or with a numerical increase in one region at the expense of another E Fischer found a normal numerical distribution in all segments of the spine to occur in only 30 per cent of spines examined Bardeen found numerical variations in from 15 to 16 per cent of the spines of all human beings and the greatest variation appears to occur in the thoracolumbar and the lumbosacral regions Having studied, carefully, the numerical variations of the spine, Rosenberg reached certain definite conclusions as to the phylogenetic development of the spine He believes that, as evolution proceeds, the sacrum moves craniad and, therefore, the sacralization of L 5 might be a quite normal phenomenon Many others, including Adolphi and Stieve, do not agree with this hypothesis, but there seems to be general agreement that these spinal variations should not be considered as malformations or as degenerative changes (Naegele, H Frey) On the contrary, they reflect, most likely, the tendency of the spine to better adaptation to the erect position Weiss believes that the number of the presacral vertebrae is determined by the level at which the extremities originate

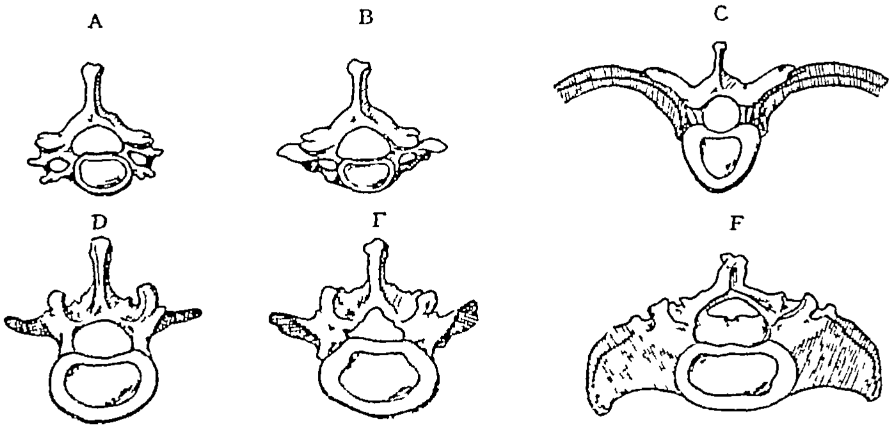


Fig 89 Participation of the ribs in the formation of the vertebrae The elements of costal origin are cross-hatched (A and B) cervical vertebrae (C) thoracic vertebra (D and E) lumbar vertebrae (F) sacrum (after Dwight)

According to Kuhne, anomalies of the spine are nearly always associated with analogous anomalies of the thoracic cage, the spinal nerves, the musculature and the pleura The anomalies may be of an ascending type (transformation of a lumbar to a thoracic vertebra) or of a descending type (sacralization of a lumbar segment) The ascending type rarely involves more than one or two segments, while

several may be affected in the descending type Meinoldi (and others) has observed that this change is usually unidirectional, *i e*, either the ascending or the descending type of variation prevails Heredity is a factor which determines the directional character of these vertebral variations, and the ascending type seems to be more common (Kuhne, E Fischer, Wanke)

The morphologic changes which occur with these variations rarely involve the vertebral bodies, and they occur mainly in the vertebral arches and especially in the transverse processes The recognition and the classification of these variations rests largely on the recognition of the rib-shaped transverse processes and the orientation of the small vertebral joints (Schertlein) Only one-half of the vertebral arch may be affected and this fact, plus the existence of anomalies of one-half of a vertebral body (chapter II A 3) may indicate that each half of the spine enjoys a certain autonomy (Stieve)

1. Variations in the occipitocervical region

In the developmental process by which the primitive cervical segments are formed, the three segments above the atlas participate in the formation of the occipital bone Occasionally, a part or all of the atlas may become a part of the occiput, with a resulting firm synostosis between the atlas and the occipital bone The axis thus becomes the first movable cervical vertebra Le Double's bibliography includes several cases of this sort, and these have been described in some detail Additional cases of occipitalization of the atlas have been observed in anatomic specimens and have been described by Allan, Braus, Correia, Kollmann, Schiffner, et al Since radiographic visualization of the atloido-occipital region is extremely difficult, not too much reliance should be placed on those cases which have been recognized in living subjects (Bézi, Feil, Ferrari, Grisel and Apert, Rose, Schüller and others) Reisner has described a case of atloido-occipital synostosis associated with other anomalies of the atlas Malformations in the occipitocervical area may give rise to serious complications as described by Brocher, Morcier and Tissot A very rare anomaly, which has not been observed during life, has been described by Kollmann as "occipital vertebra" It appears as a bony protuberance on the occipital bone and resembles the posterior arch of the atlas

Additional bibliography Dwight, Decker and collaborators, Latarjet, Macalister, Regnault, Solger, Uhde and others

2. Variations in the cervicothoracic region

The most common variation in the cervicothoracic region is the presence of unilateral or bilateral cervical ribs According to Meyer-Burgdorff, cervical ribs are present in from 0 5 to 1 0 per cent of all persons and Rischel has found the frequency of unilateral cervical ribs to be as high as 2 4 per cent They are usually observed at C 6 or C 7 and are rarely present at a higher level (Völker C 5, Fischel C 4 and higher, Szavolski bilateral C 4) Bilateral cervical ribs are sometimes described as "dorsalization of C 7" The various cervical ribs have been classified by Grezzi and Gruber For the anatomist cervical ribs are insignificant variants from the normal, but for the clinician they are potential etiologic factors in the production of a series of symptoms, occurring (it is estimated) in from 5 to 10 per cent of all persons bearing cervical ribs (Agrifoglio, Husselrath, Meyer-Burgdorff, F Putti, Robinson, Stone and Ebbiot, Serck-Hanssen)

Cervical ribs are not always completely ossified and, at times, only the posterior portion of the rib will be osseous, the remainder being a dense fibrous band inserted into the sternum The clinical manifestations are the same whether the rib is completely ossified or partially fibrous Surgical removal of the rib or the fibrous band may be necessary For the relationship of the cervical rib and the scalenus syndrome one should consult Wanke and his bibliography

A variation sometimes found in a transitional vertebra of the cervicothoracic region is the presence of a foramen in the transverse process (the transverse foramen), a finding observed normally only in a cervical vertebra

3. Variations in the thoracolumbar region

The lumbar rib is the anomaly most frequently encountered in the thoracolumbar region (fig 90) Since it is rather easy to confuse a lumbar rib with a fractured transverse process, it is important to be familiar with this anomaly, and there is an extensive literature available regarding this subject

(Albanese, Andersen, v Hayek, Meyer-Burgdorff, Mainoldi, Schertlein and others) In agreement with Meyer-Burgdorff we distinguish between two types of lumbar ribs a thoracic type with all of the characteristic features of a normal rib, and with a poorly developed transverse process, and a lumbar type with articulation of a rudimentary rib with hypertrophied transverse process Mainoldi

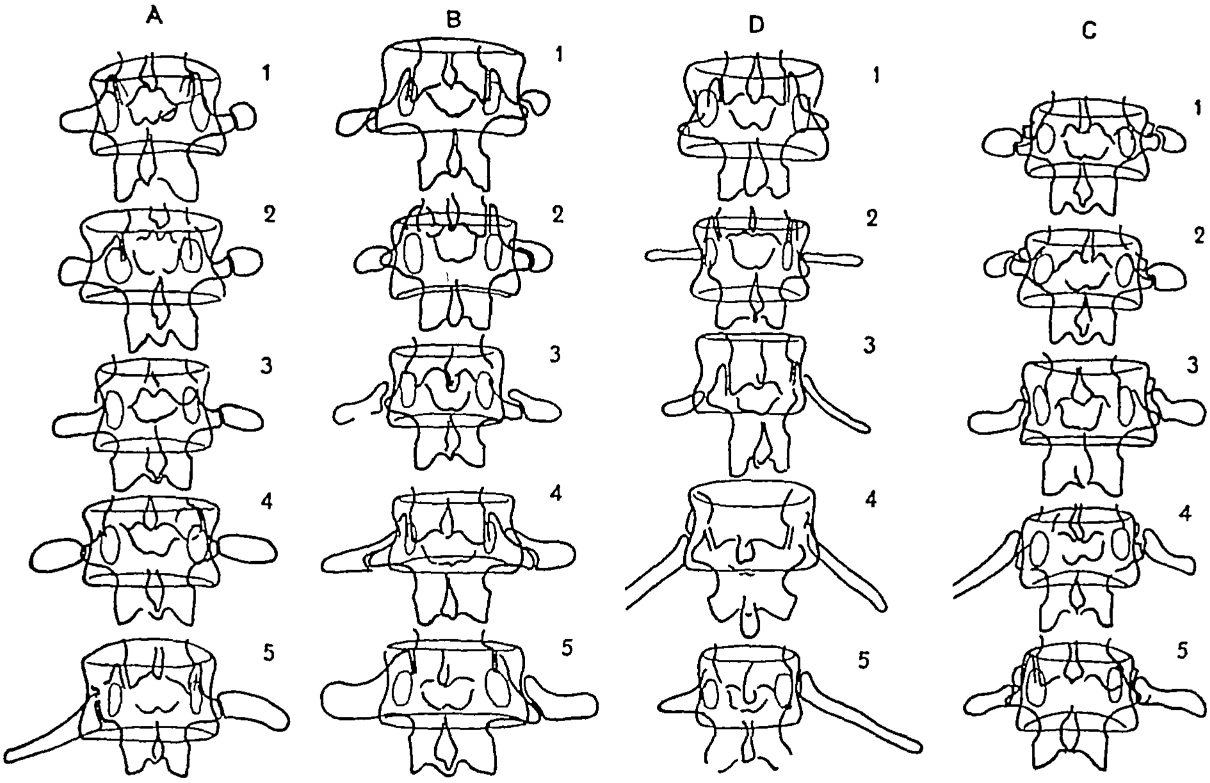


Fig 90 Various forms of lumbar ribs (after Schertlein)

finds the thoracic type to be slender and pointed, with its course directed obliquely downward and laterally The lumbar type he finds to exhibit a horizontal (or even slightly upward) course, and to have a rounded distal end (Aichel, Albanese) Heise, Hayek and Schertlein have suggested additional subdivisions of these forms, but their subdivisions tend to overlap All of these variants may occur unilaterally or bilaterally and frequently they may differ on the two sides

Fig 91 Left transverse process of L 5 shows a bony tubercle indicating beginning of a transitional vertebra

Lumbar ribs are of more frequent occurrence than cervical ribs Hueck found anomalous ribs to be present in 7 75 per cent of spines examined and found that 75 per cent of these are of the lumbar type Their only importance is in differential diagnosis of fracture of a transverse process Morandi has described elongation of the transverse process without the formation of a lumbar rib

Changed orientation of the articular facets (see p 45) is a not infrequent variation in the thoracolumbar region Normally, the orientation of the surfaces of the facets of T 12—L 1 is that typical of the lumbar spine, while the orientation of the facets of T 11 and T 12 is that usually seen in the thoracic spine A shift may occur either craniad or caudad and unilateral difference in orientation may be present Schertlein found that with bilateral lumbar ribs the facets are oriented usually as in the lumbar vertebrae

4a. Variations in the lumbosacral region

Fig 92 Unilateral sacralization of L 5 Hypertrophied left transverse process forming a pseudoarticulation with the ala of the sacrum

Rosenberg's numeration makes the twenty-fourth vertebra the last presacral segment and the twenty-fifth the first sacral vertebra (p 48) These two vertebral segments are subject to great variation, and these variations are commonly known as "sacralization" and "lumbarization" Sacralization is said to be present when the last presacral vertebra approximates the form of one or both sides of the alae of the sacrum or when the entire vertebra fuses with the sacrum Lumbarization indicates separation of the first sacral segment on one or on both sides without much change in its form, or when in greater or lesser degree it approaches the form of L 5 It is not always possible to decide whether such a "transitional" vertebra results from sacralization or lumbarization, the deciding of which requires the enumeration of the entire series of vertebral bodies It will suffice, however, for anatomic and clinical purposes to describe such a transitional segment as a "lumbosacral transitional vertebra" Thus one may avoid the counting of the sacral and coccygeal segments (Lubke found 6 fused sacral vertebrae to be present in 31 per cent of all persons) We may also dispense advantageously with counting the sacral foramina since some of them exhibit no lateral bony walls

The statistics relative to the frequency of occurrence of a transitional lumbosacral vertebra vary between 0 6 to 25 per cent, and those depending on racial characteristics are even more divergent (0 7 per cent and 45 per cent) Since these statistics denote different methods of examination they are scarcely capable of

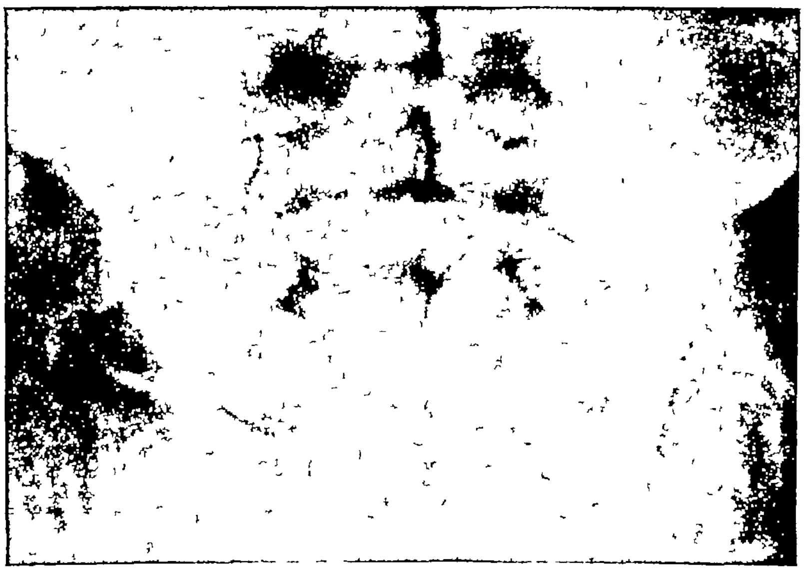


Fig 93 (left) Photograph of posterior surface of a macerated specimen of the lumbosacral spine Male, 58 Transitional vertebra Marked hypertrophy of left transverse process of L 5 forming a pseudoarticulation with the ala of the sacrum Osteophyte formation on the lumbar vertebrae

Fig 94 (right) Lumbosacral transitional vertebra with marked hypertrophy of the left transverse process forming a pseudoarticulation

comparative evaluation Some of the figures were obtained from the study of anatomic specimens while others represent radiographic observations, mostly from studies of the urinary tract Only rarely were they derived from careful anatomic studies such as those made by Lubke in Schmorl's Institute

The statistics commonly cited, and especially those compiled from radiographic material rarely mention the total number of vertebrae in a given spine and, consequently, it is nearly impossible to differentiate between sacralization and lumbarization The discrepancy in the figures, reflecting sex preponderance of either of the variants, appears to reflect the uncertainty of the various writers on the subject Blumensaat and Clasing, both surgeons, find the variation more common in men, but Martius, an obstetrician, finds them more often in women

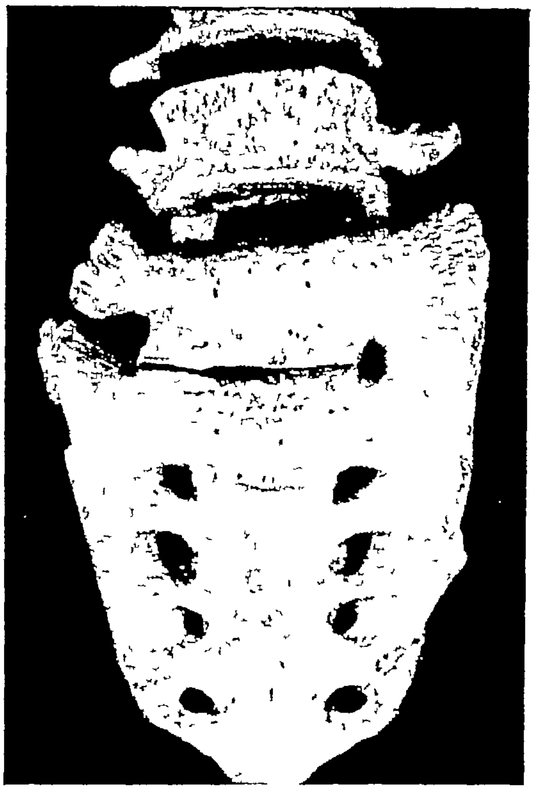


Fig 95 (left) Photograph of the anterior surface of the lumbosacral spine Macerated specimen Male, 38 Left unilateral sacralization and marked narrowing of the L 5—S 1 disc space

Fig 96 (right) Photograph of the anterior surface of the lumbosacral spine Woman, 26 Macerated specimen Transitional lumbosacral vertebra The hypertrophied transverse processes of L 5 have not yet formed a pseudo articulation with the sacrum

Some radiologists have attempted to obviate the necessity of complete enumeration of the vertebrae by the establishment of morphologic criteria for each lumbar vertebra Thus Brandt finds that the transverse processes of L 3 and L 4 show definitive features while Hohtsch uses L 4 as his point of reference He finds that the transverse process of L 4 is shorter and thinner than that of L 1 or L 3 and has a pointed extremity and is turned slightly upward, while its inferior border exhibits a lenticular concavity The hypotheses of Brandt and Hohtsch were not confirmed by Friedl, and the whole subject requires additional study

The confusion in the terms sacralization and lumbarization, and the difficulties encountered in the enumeration of the vertebrae, explain the marked discrepancy in the statistical data (see tables 2 and 3) Some writers consider any hypertrophy of the transverse process to represent sacralization. Others think that the process must be enlarged and costiform, and must turn downward in its course, if it is to be regarded as indicative of sacralization, and numerous classifications have been proposed for the orderly arrangement of the numerous types of transitional lumbosacral vertebra Since these appear to be founded on clinical findings radiographic features or developmental aspects, no very sound classification has been established Le Double describes 6 types of transitional lumbosacral vertebrae Six types are also recognized by Meyer-Borstel, who, however, does not include a lumbarized vertebra Weiss distinguishes a first and second degree of transitional vertebra, and Imbert and Katalorda's classification includes three groups, based entirely on radiographic

Table 2

Indicence of sacralization per 100 spines

Goljanitzki	0 6	Turner	5 0
Lubke	1 0	Brailsford	8 1
Hirsch	1 3	Ikljaracik	9 0
Sachs	1 7	Giles	9 2
Rossi	2 0	Martius (men)	9 5
Blumensaat and		Imbert	10 0
Clasing	2 8	Vasiljeva	11 0
Moore	3 8	Martius (women)	12 0
Leri	4 0	O'Reilly	13 0
Roccavilla	4 0	Schuller	23 0
Hueck and Heise	4 2	zur Verth	25 0
Meyer-Burgdorff	4 5	Ingebrigtsen	25 0

Table 3

Racial incidence of sacralization per 100 spines

Laplanders	0 7	(Ingebrigtsen)
Europeans	4 0	(Mauclaire and Flips)
Russians	5 0	(Turner)
Norwegians	5 3	(Ingebrigtsen)
Fuegians	41 0	(Albanese)
Primitive races	45 0	(Bohart)

Table 4

Incidence per 100 spines

	Sacralization	Lumbarization	Total
Hirsch	1 3	2 4	3 7
Blumensaat and Clasing	2 8	2 2	5 0
Hueck and Heise	4 19	1 33	5 52
Lubke	1 0	9 0	10 0
Léri	4 0	6 0	10 0
Kummel and Kautz	—	—	10 0
Martius (women)	12 0	8 0	20 0
Vasiljeva	11 0	11 0	22 0

Table 5

Incidence of back pain in sacralization per 100 spines

Aimes and Jacques	25 0
Léri	53 0
Imbert and Catalorda	60 0

findings Because of the increasing clinical importance of the presence of transitional vertebrae, a new classification based on anatomic features seems to be necessary The classification of Blumensaat and Clasing recognizes three groups

Group I Complete sacralization (i e , complete synostosis of the twenty-fourth vertebral segment with the first sacral segment) Complete lumbarization (i e , separation of the first sacral segment which becomes L 6)

Group II Incomplete sacralization and lumbarization

a) Asymmetric synostosis with partial fusion (either unilateral or bilateral) with the adjacent vertebra
b) Hemisacralization or hemilumbarization
c) A combination of incomplete sacralization and lumbarization

Group III Transitional form of a transverse process with costiform hypertrophy, but without fusion with the sacrum

Fig 97 (left) Photograph of macerated specimen Bilateral sacralization with pseudoarticulations

Fig 98 (right) Radiograph of the lumbosacral spine Transitional vertebra with bilateral pseudoarticulations

Fig 99 Photograph of a macerated specimen of the lumbosacral region of a 64 year old man Anterior view Transitional lumbosacral vertebra Pseudoarticulation on the right with hypertrophic spurs and synostosis on the left

A defect in this classification is the retention of the terms "sacralization" and "lumbarization," a distinction not always possible It does include, however, the possible variants of a lumbosacral transitional vertebra costiform hypertrophy of a transverse process, unilateral or bilateral synostosis of the transverse process of L 5 and the lateral mass of the sacrum and complete synostosis

Articulation of the transverse process of a transitional vertebra with the lateral mass of the sacrum is of clinical, radiologic, and anatomic importance (fig 93) Such an articulation, whether a true articulation or a synarthrosis, is subject to degenerative changes with osteophyte formation, osteosclerosis, etc , as is any other articulation Synovial bursae may occur between the articular processes of a transitional vertebra and the lateral mass of the sacrum (Martius) The variable anatomic aspect of a transitional vertebra results from the great frequency of unilateral and asymmetric variants (figs 91—95) as compared to symmetric and bilateral variants (figs 96—98) In Reisner's series of 222 transitional vertebrae (4 9 per cent of 4500 skeletons) he found the following distribution complete unilateral 33 per cent, unilateral with articulation 40 per cent, complete bilateral 16 per cent, bilateral with articulations 7 per cent, complete on one side with contralateral articulation 4 per cent Brailsford found sacralization in 8 1 per cent of subjects with 3 4 per cent unilateral and 4 7 per cent bilateral sacralizations Giles's figures are almost identical 4 2 per cent unilateral and 5 per cent bilateral Blumensaat and Clasing found sacralization to be predominantly unilateral, and lumbarization to be

Fig 100 (left) Photograph of the anterior surface of a macerated specimen of the lumbosacral region Elderly man Transitional lumbosacral vertebra with bilateral pseudoarthrosis Marked osteophytes bridge the right side of the pseudoarticulation and a part of the sacro-iliac joint Osteophytes on the vertebral bodies

Fig 101 (right) Photograph of the anterior surface of a macerated specimen of a 72 year old woman The sacrum consists of six segments One transitional lumbosacral vertebra

usually bilateral, and these observations coincide with those of Willis An asymmetric unilateral transitional vertebra may produce a marked scoliosis by vertebral torsion and rotation Reports in the literature indicate that congenital scoliosis of the lower portion of the spine is frequently produced by a unilateral lumbosacral transitional vertebra, but study of Schmorl's collection of

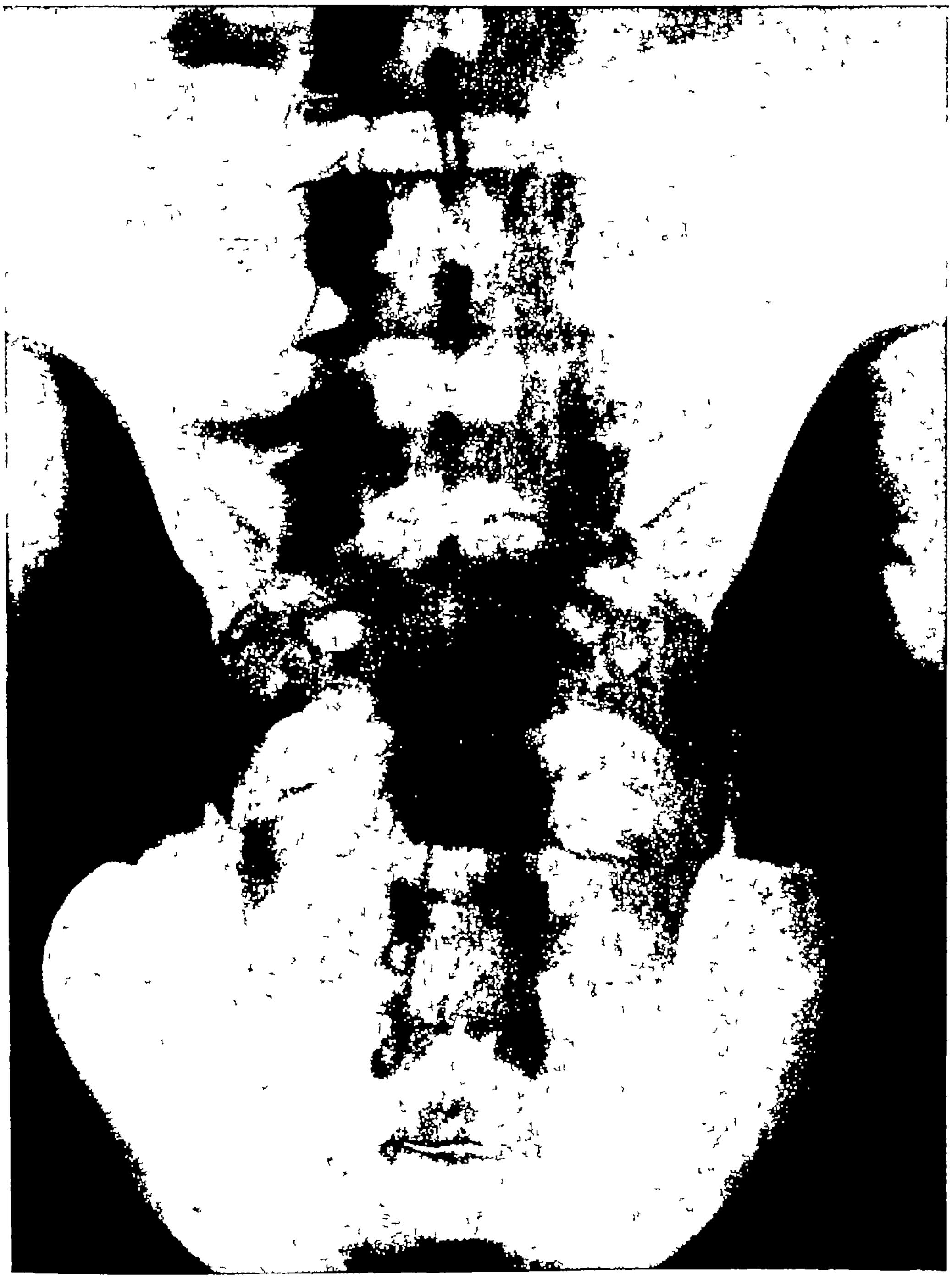


Fig 102 Radiograph of a sacrum with six segments Sacrococcygeal synostosis on the left Sacral alae extend above the base of the sacrum (see fig 103)

skeletons indicates that lumbosacral scoliosis is less frequent than would appear from the literature The height of the uninvolved side of a unilaterally sacralized vertebra quite often is reduced (Blumensaat)

An unusual case of unilateral sacralization was seen in radiographs described by Rövekamp The lumbar transverse processes on one side were enlarged so markedly that they articulated with each other A radiograph by Györgi showed the transverse processes of L 1 to L 5 bridged, unilaterally, by a continuous bony band It is possible however, that these findings might represent

myositis ossificans rather than a congenital variation Hypertrophy of several transverse processes was described by Meves (cf fig 81)

The variations which occur in the lumbosacral region involve not only the vertebral bodies and the transverse processes, but also the small vertebral joints Depending on the degree of adaptation of the transitional vertebra, the small vertebral joints may be ossified unilaterally or bilaterally, or they may be only asymmetric Below the transitional vertebra the intervertebral disc is commonly reduced in height, and may be present only as a vestigial remnant (fig 95) In the presence of true lumbarization, the disc below the transitional segment may be of increased height (Blumensaat and Clasing) Not infrequently the vertebral canal assumes a triangular shape on cross-section (as in the sacral region), and the spinous processes may resemble the small crest-like protuberances observed on the sacrum It is interesting to note that, in an anatomic specimen, there is no appreciable narrowing of the intervertebral foramen between the transitional vertebra and the sacrum (Blumensaat and Clasing) The relationship of transitional vertebrae and the form of the pelvis, especially important in obstetrics, has been discussed by Kirchhoff Imhäuser found that many persons with a transitional lumbosacral vertebra were subject to some disturbance of the hip joint

Numerous changes associated with the transitional vertebrae (formation of pseudoarthrosis, scoliosis, narrowing of the vertebral canal and narrowing of the disc space) and their possible relationship to low-back pain have been studied repeatedly Bertolotti and de Rossi were the first to point out this back pain syndrome, but their theories were opposed for many years by various German writers (Schüler and others) However, over a period of time, the relationship of pain to sacralization became recognized, with general agreement, that the pain did not depend simply on the presence of a transitional vertebra, but to the secondary changes in the spine These changes include arthrosis of anomalous joints, inflammation of synovial bursae, periostitis, static changes associated with scoliosis, etc Fineschi thinks that compression of a nerve root by a somewhat narrowed intervertebral foramen is not a source of pain, but that it results instead from the prolapse of disc tissue Myelodysplasia, already discussed in relation to spina bifida, is unlikely to develop since the variation affects primarily the transverse processes The bibliography which follows includes discussions of various forms of therapy including the results of the surgical removal of enlarged transverse processes of a transitional vertebra Alexandrow, Belden, Bohm, Blumensaat and Clasing, Buto, Bermond, Beck, Chevalier, Chinescu with Valeanu and Ghimpedeanu, Ettore, Feuereisen, Gabetti, Gref, Heidsieck, Hohmann, Ingebrigtsen, Junghanns, Kleine, Königswieser, Lefort and Ingelrans, Léo, Martius, Menard, Meyer-Borstel, Meixner, Mitchell, G Müller, W Muller, Oleaga, Philipp, Perrin, Putti and Scaglietti, Rohrbach, Rowold, Rutkowski, Rybak and Stern, Scheuer, Schrader, Scaglietti, Stork, Talia, zur Verth, Warner, Weil and Dam, Weiss, Wenzl, Wreden, Zanoli and others

4b. Pseudosacralization (acquired lumbosacral transitional vertebra)

The occurrence of an articulation between a transverse process and the lateral mass of the sacrum does not always result from a congenital variation, but may represent the approach of the transverse process to the ala in the course of a pathologic process Lübke found such articulations in 10 per cent of his material, mainly in persons more than 60 years old When the lowermost presacral disc loses its height to a considerable degree, as a result of degenerative changes, or when the lowermost presacral vertebra is reduced in height following fracture or osteoporotic collapse, a joint may be formed between a quite normal transverse process and the ala of the sacrum Depending on the shape of the alae of the sacrum, which may be horizontal, directed upward or directed downward, the pseudoarticulation may be at the level of the L 5—S 1 intervertebral space, above it or below it The occurrence of the pseudoarticulation is more frequent when the upper surface of the lateral mass is directed upward Sometimes quite marked degenerative changes may involve the newly formed joint and differentiation between a congenital variation and "pseudosacralization" may be difficult

4c. Ossification of the iliolumbar and the lumbosacral ligaments

The iliolumbar and the lumbosacral ligaments are strong bands of dense fibrous tissue attached to the tip of the transverse process of the last presacral vertebra As they pass laterally they spread to attach themselves to the iliac crest (the iliolumbar ligament) and to the anterior surface of the ilium and base of the sacrum (the lumbosacral ligament) Ossification of these ligaments may produce a radiographic picture resembling a transitional vertebra (fig 104) The relation of this

ossification to the various anomalies is unknown It may be seen in very young persons, and while some writers consider an inflammatory process to be a prerequisite, others disagree and believe the ossification to be of congenital origin (Blencke, George and Leonard, Simon) Additional cases and bibliography Doub, Bockelmann and Kreuz, Janker, Junghanns, Lehmann, Lowman, W Müller, Odessky, Reisner, Schredl, Sorge

5. Variations in the sacrococcygeal region

Transitional vertebrae in the sacrococcygeal region are of slight clinical importance and have received but little attention in the radiologic literature Variations in this area, which may result from either craniad or caudad shift, occur quite frequently and are seen in from 5 to 14 per cent of cases (Adolphi, Frets, Paterson, Stieve) An incomplete wall of either or both of the lowermost sacral foramina is a common finding, and is associated

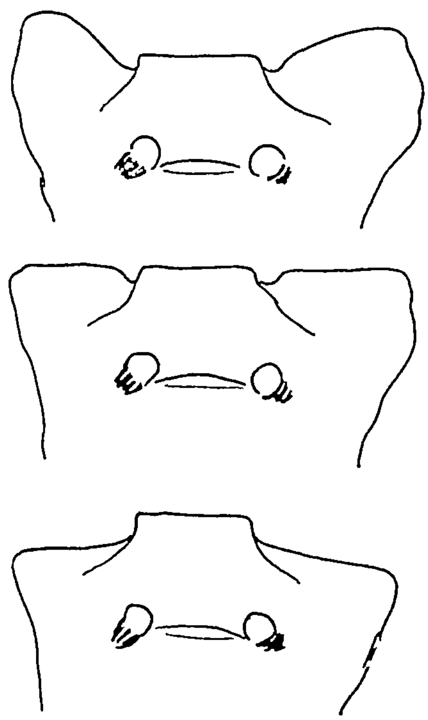


Fig 103 (left) Diagrammatic presentation of the various configurations of the alae of the sacrum in relation to the superior vertebral plate of S 1

Fig 104 (right) Radiograph of the lumbosacral area Bilateral calcification of the iliolumbar ligament extending from the transverse processes of L 5 to the iliac crests (after Reisner)

with transitional vertebra of either the cranial or caudal variety Rosenberg and others have described numerous types of variants (see fig 101)

Occasionally, the normal concavity of the coccyx does not appear and the coccyx protrudes posteriorly, resembling a tail The number of the coccygeal elements remains normal, but the coccyx as a whole is elongated by enlarged segments (Hornitzki, et al)

D. Complex vertebral anomalies

In the foregoing discussion of spinal variations and malformations, we have attempted a classification based on the developmental aberrations which produced them However, this has not always proved to be possible because of the great complexity of the developmental process It is difficult frequently to assign a given malformation to the groups which we have described, since they result from aberrations in various phases of development These compound malformations are quite common and are found frequently in stillborn infants (figs 105 and 106), but they are observed also in adults (figs 107 and 108) The enumeration of the possibility of such malformations is beyond the scope of this monograph Occasionally, one may encounter areas of the spine in which there are such extensive variations that it becomes practically impossible to analyze the component elements (Giannini with Borrelli and Greenberg, and others) Fusion of the vertebral

bodies and arches, a greater or lesser number of spinal segments, hemimetameric segmental displacement, and various other types of variations which may appear in any portion of the vertebral column may markedly impair the mobility of the involved area, and disturb its statics Such compound malformations of the cervical spine (Klippel-Feil) are of particular importance and will be discussed in some detail

1. Klippel-Feil syndrome (short neck)

In 1912 Klippel and Feil described a form of compound malformation of the lower cervical spine consisting of extensive fusion, producing marked shortening of the cervical spine ("short neck,"

Fig 105 (left) Anteroposterior radiograph of the head and trunk of a newborn Fusion of several cervical vertebrae Dehiscence of several thoracic vertebrae Flattening and widening of the lower thoracic vertebrae

Fig 106 (right) Anteroposterior radiograph of the spine of a newborn Several cleft vertebrae in the lower thoracic and upper lumbar region with fusion of some of the ribs and absence of some vertebrae Marked kyphoscoliosis

"frog neck"), and subsequently, numerous cases were reported The mechanism of development of the Klippel-Feil syndrome remains a controversial subject Feller and Sternberg found that in the various malformations of the cervical spine, there is a regularly associated nonfusion of the vertebral arches and malformation of the occipital bone with prolapse of the medulla The case published by Esau supports the hypothesis of association of nervous system disturbances Guillain and Mollaret found, in certain patients with a Klippel-Feil syndrome, a paralysis resembling that produced by section of the spinal cord and resulting from malformation of the cervical spine They believe, however, that the damage to the nervous system may be secondary to vascular compression caused by the deformity (Foggie, Vet and Tans) Rozowa-Muchina has described generalized platospondylia associated with the Klippel-Feil syndrome Frequently, this syndrome is associated with other malformations Sprengel's deformity, cervical ribs, neck deformity, etc (Böhm, Ingelans and Piquet, Kufferath Fusari, Heidecker, Schwarzveller, etc) It is possible that this syndrome does not

Fig 107 Anteroposterior radiograph of the spine of a 45 year old woman "Butterfly vertebrae" of T 7 to T 10 Suggested "butterfly vertebrae" of L 1 and L 2 Fusion of T 11 and T 12

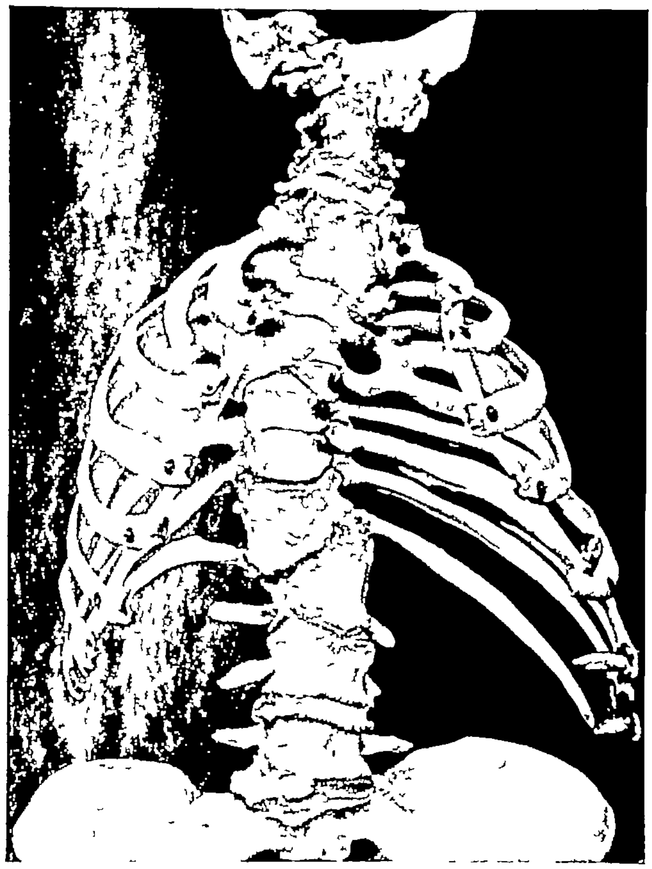


Fig 108 Photograph of the malformed spine of a 52 year old man Several hemivertebrae Block vertebrae Scoliosis Fusion of ribs (specimen in the Museum of Pathology in Berlin Professor Rossle)

represent an actual congenital malformation but may, instead, result from an intra-uterine inflammatory process or fusion Kallius considers the Klippel-Feil syndrome as irregular fusion of the malformed vertebrae into a single cervical block He stresses the fact that not all fused components of the cervical spine should be regarded as part of a Klippel-Feil syndrome The findings of Feller and Sternberg concerning concomitant neurologic disturbances should receive particular attention

Bibliography Baumann, Beddiges, Canigiani, Dodds, Elowson, Feil and Lebleu with Fischer, Grunwald, Greenberg, Kallius, Kunert, Lenk, Odèn, Partsch, Pytel and Sajevic, Rechtman, Schulz, Schwarze, Smeesters, Timmerkamp, Ullox and Gondoc, Walter, Weninger et al

III. Pathologic Changes of the Osseous Spine

Considered from a practical standpoint, lesions of the osseous spine and those of the disc-ligament components must be considered separately. Because of the relation which exists between disc and vertebra, it is rare that a pathologic process affects only one of them, and sooner or later, a disease which affects one will involve the other and will lead to morphologic and functional changes. Consequently, a certain repetitiousness, with references to previous descriptive passages and to chapters still to come, seems unavoidable. The lesions which affect the spine as a whole will be discussed separately.

There is no easy classification of the less common bone disorders to which the spine is subject, since we know but little of their etiology and pathogenesis and since considerable research in this field is needed. Our knowledge is especially limited in the field of the interaction of such etiologic factors as hormones, metabolic disorders, nutrition and infection.

A. The osteoporoses (bone atrophy)

Osteoporosis is the most frequent of the various osseous changes. Although its etiology and its clinical and pathologic features are by no means uniform, and although it may represent the end state of quite diverse pathologic processes (fig. 109), its radiographic manifestations are quite unvarying and consist essentially in a reduction in the number and the size of the trabeculae which are so important in the production of the radiographic image. In the spine such a reduction decreases the tensile strength of the vertebral bodies, with consequent changes in their shape, and alteration of the spinal curvatures. The senile type of osteoporosis is, by far, the most common and will be discussed (p. 62) in some detail. The other forms of osteoporosis will be considered briefly.

If we wish to understand the life and development of bone, and especially the relationship between the various osteoporoses and the etiologic factors which gave rise to them, we must not regard bone as a simple inert framework for weight-bearing and similar mechanical functions. On the contrary, we must observe its continual rebuilding, and its function as a metabolic organ constantly storing and replacing minerals and with a selective action in the metabolism of calcium and phosphorus (Uehlinger) comparable to the action of the liver in the metabolism of glucose (Schüpbach). Albright has shown (fig. 110) that, in general, there are three groups of hormones which exercise a regulatory action on the osteoclastic and osteoblastic processes in bone. Hormones produced *in the sex glands* of either sex, *i. e.*, the estrogenic and androgenic hormones, stimulate osteoblast formation and thus increase osteogenesis. The second group consists of the adrenocortical hormones, the protein anabolic or "N" hormones, produced by the adrenal cortex and similar in structure to the sex hormones, both male and female. These hormones also stimulate osteogenesis. The third group, also of adrenocortical origin, are the "S" hormones (S = sugar) which stimulate the process of the production of glucose from the amino acids. The S hormones inhibit the activity of the osteoblasts and deplete the bone matrix of proteins, thus leading to osteoporosis, while both groups of sex hormones have an antiosteoporotic action.

During the period of sexual maturity the actions of various hormones are in equilibrium, so that the activity of the osteoblasts and osteoclasts is balanced. Of the three groups of hormones the S hormone is secreted during the entire lifetime, whereas the sex hormones which are produced by the sex glands and the adrenal cortex are subject to variations depending upon the age of the individual. A decreasing production of sex hormones with advancing age and the normal secretion of the S hormone results in hormonal imbalance leading to osteoporosis. In women, this process occurs at the menopause when the production of estrogenic hormones ceases, and there is a decrease in the amount of the N hormones (adrenocortical hormones) secreted, while at a comparable age in men

there is a decrease in the activity of Leydig's cells and the failing production of androgens Figure 110 demonstrates the influence of hormone secretions on bone metabolism in both sexes and at various periods of life When there is a precocious decrease in the production of androgen and estrogens, a presenile osteoporosis may result, and this process will be considered with the "hormonal osteoporoses" (p 66)

Although Albright's theory has not met with general acceptance, it seems to us to offer an acceptable explanation of many poorly understood aspects of bone metabolism, and we believe that investigation of this whole subject should be continued (Jesserer and Hörtnagel) From the standpoint of therapy, the recognition of the role of hormonal imbalance in osteoporosis represents a distinct advance in our knowledge, and we are no longer helpless but may effect decided improvement with appropriate hormone therapy We say "appropriate" to emphasize the fact that osteoporosis may be produced by the too zealous use of hormones, as Curtis with Clark and Herndon have shown in connection with the use of cortisone and ACTH (chapter III G 2)

It is Albright's belief that osteoporosis results from an insufficiency of androgenic or estrogenic hormones due to the involutional phenomena of aging and due to physiologic disturbances which lead to a decrease in osteoblastic activity without a corresponding decrease in the normal activity of the osteoclasts (fig 109) Osteoporosis following decreased activity of the osteoblasts is a true bone atrophy with the quantitative and qualitative decrease in bone trabeculae found in the osteoporosis of disuse, senile osteoporosis, menopausal osteoporosis, osteoporosis of ovarian or of testicular insufficiency and that seen in Cushing's disease, in which the osteoporosis results from an overproduction of the S hormone (p 71)

According to Labhart and Schupbach the sex hormones (which are lacking

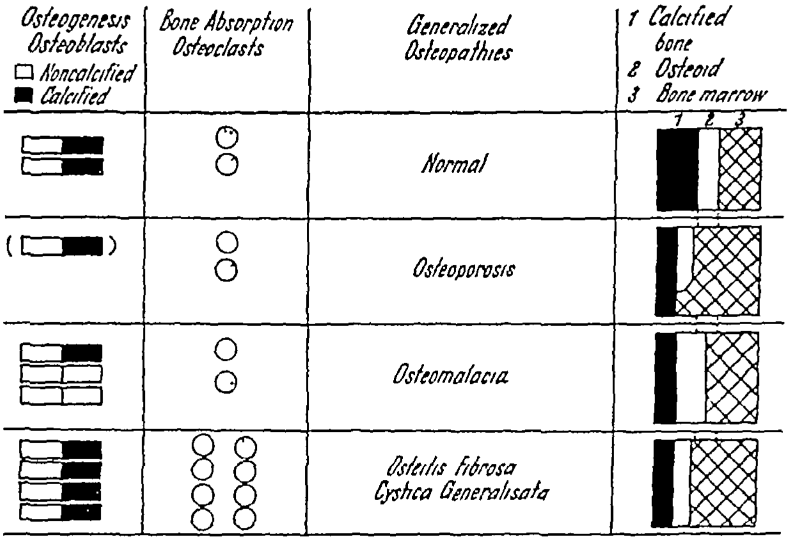


Fig 109 Schematic survey of osseous transformation in various generalized osteopathies (left column) with identical radiological manifestations (right column) In a normal bone the osteoid is continuously ossified The bone absorption and new-bone formation are in equilibrium In osteoporosis the formation process of bone decreases while bone absorption continues normally In osteomalacia there is an intense proliferation of osteoid, but its calcification is impaired In osteitis fibrosa cystica generalisata (Recklinghausen) new-bone formation is increased, but there is an accompanying marked increase in bone absorption

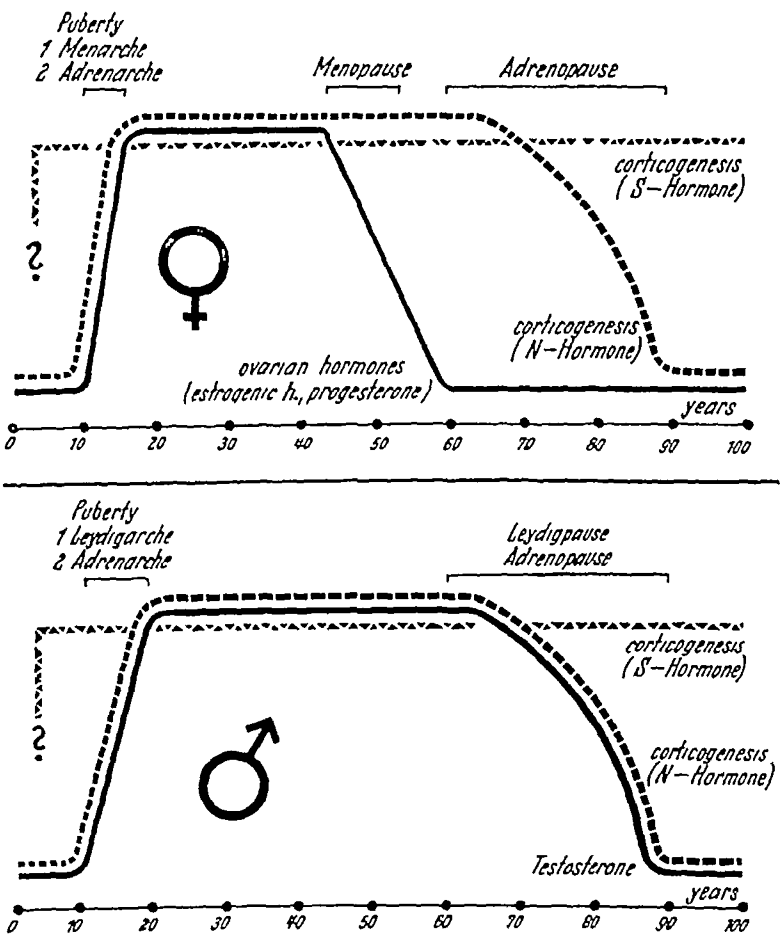


Fig 110 Effect of sex hormones on bone metabolism in men and women (after Albright)

in part or in whole in those forms of osteoporoses) stimulate the anabolism of bone and particularly, the osteoblastic activity The fixation of various inorganic substances (nitrogen, phosphorus, calcium) is stimulated secondarily by osteoblastic activity

It is curious to note that osteoporosis is much more common in the spine than in other parts of the skeleton and may involve the spine exclusively For this there are several explanations One must admit, for example, that there is a directed hormonal action which affects certain portions of the skeleton of which the changes in the pelvis occurring during pregnancy afford a well known example Our experience indicates that there must be a directed and selective hormonal action affecting the spine and pelvis in the endogenous osteoporoses The rich blood supply of the spine, and the active hematopoietic function of the spinal marrow are additional factors The rich vascularization encourages rapid metabolism and quick response to the calcium needs of the organism, whether these needs are physiologic or pathologic Thus, quantitative and qualitative decrease in the bone trabeculae occurs more readily in the spine than in the long bones The third cause of the rapid response of the spine to generalized disease and to the wear and tear of the aging process is the constant stress to which it is subjected Never, even while sitting or lying in bed, is the spine relaxed to the extent experienced by the other portions of the body This continuous stress serves to explain the early appearance of pain in the spine in generalized diseases of bone, and certainly is the case in osteoporosis and the various disorders of the reticuloendothelial system

1. Senile osteoporosis

The most striking feature of an osteoporotic vertebra is the quantitative and qualitative decrease in the bone trabeculae The bone lamellae which, in youth, form a firm dense network (fig 23) become thin and few in number (fig 111) The vertebral plates, usually well developed, and sometimes reinforced by a compact bony layer, exhibit an increased number of perforations and marked thinning, reflecting decreased osteoblastic activity combined with normally maintained bone absorption (fig 109)

The gross changes of osteoporosis (rarefaction, thinning of the trabeculae, collapse of the vertebral body and sometimes callus formation) are recognizable in the radiograph According to Babaiantz, decalcification must amount to more than 50 per cent to be apparent radiographically With the demineralization, the horizontal course of the blood vessels (p 2) becomes more prominent, producing linear radiolucencies (Pitzen) which must not be mistaken for fractures

The final condition of a vertebra thus weakened does not depend solely on the stresses imposed on it, but on the elasticity of the intervertebral discs and the direction of the forces acting on it These forces, which change from one section to another, depend largely on the normal and abnormal curvatures of the spine

Under the influence of the expansive force of the nucleus pulposus, the intervertebral disc exerts pressure on the contiguous vertebral surfaces This pressure, well supported by a normal vertebra, may prove too much for an osteoporotic segment and the expansion of the disc in the region of the nucleus may produce a concave defect in the adjacent vertebral plates (Schmorl) The cartilaginous plate inserted between the disc and the vertebral body surface may be stretched considerably and may give way permitting prolapse of the disc tissue into the vertebral body (Schmorl's node discussed in chapter IV B 1, figs 112 and 113) When the pressure of the nucleus pulposus is reinforced by the functional effort of the spine, the weakened vertebral body may give way, but Schmorl has shown conclusively that these changes cannot occur unless there is present a normal and intact annulus and nucleus pulposus

As a result of the expansion of the disc, the vertebral plates are depressed and, in a lateral radiograph the vertebral body appears to be biconcave (figs 112 and 114a) Sometimes one recognizes a vertebra exhibiting one normal vertebral plate and one with a deep concavity bulging into the vertebral body (figs 113, 115b) After Schmorl had reported these changes to the Orthopedic Congress of 1926 and to the Congress of Pathology in 1927, Báron and Bársony described identical cases as "vertebral bodies with central depressions" while Bohne called them "hourglass" vertebrae

Since these biconcave vertebrae resemble the vertebrae of fishes, "fish-vertebrae" is a term which has been employed to describe them (Biblio Galm, Polgar)

Although in a sagittal section of a normal spine the elasticity and internal pressure of the nucleus cause protrusion of the nucleus, this does not occur when an osteoporotic spine is sectioned because the elastic properties of the nucleus have been exhausted This phenomenon is discussed in detail in chapter IV, p 130

The central depression of the vertebral plate is produced by two factors The central portion of the cartilaginous plate receives the most direct pressure from the nucleus, and it is this area that is the thinnest and has the greatest number of perforations, while the margin of the vertebral plate consists of the very solid bony rim Göcke found that the center of the cartilaginous plate normally has only 80 per cent of the strength of the margin Moreover, the solid insertion of the spiral fibers of the annulus into the vertebral margins make it practically impossible to separate two vertebrae, if the interposed disc remains intact All of these changes are of the greatest significance in the lumbar spine, where the disc-spaces are wider than in the other sections of the spine, and where the nucleus pulposus seems to have the greatest expansile ability Also, the static pressures on the lumbar spine follow the longitudinal axis of the vertebral bodies while the normal kyphosis of the thoracic spine causes these pressures to take other directions It is for this reason that the illustrations (figs 112—115) accompanying the text refer to the lumbar spine

In the higher sections of the vertebral column, the process of osteoporosis presents a different aspect, although the changes occurring in the lowermost thoracic segments closely resemble those of the lumbar spine The upper segments are subjected to quite different

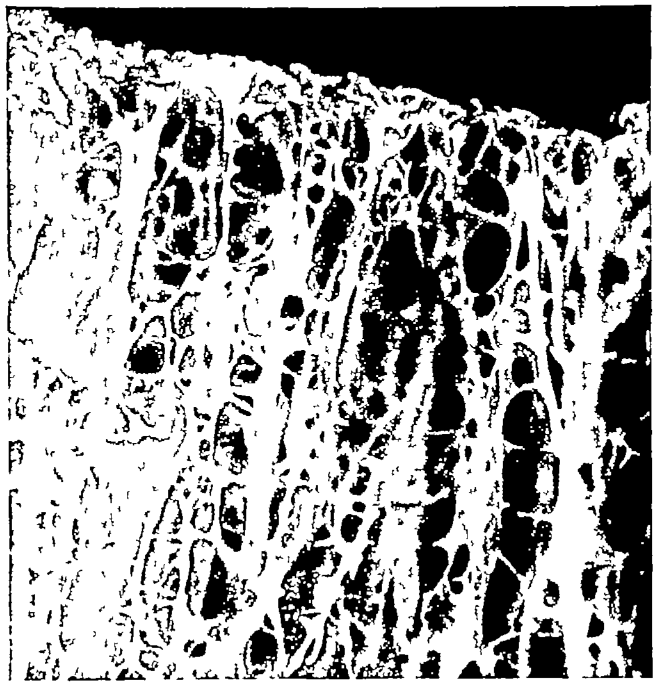
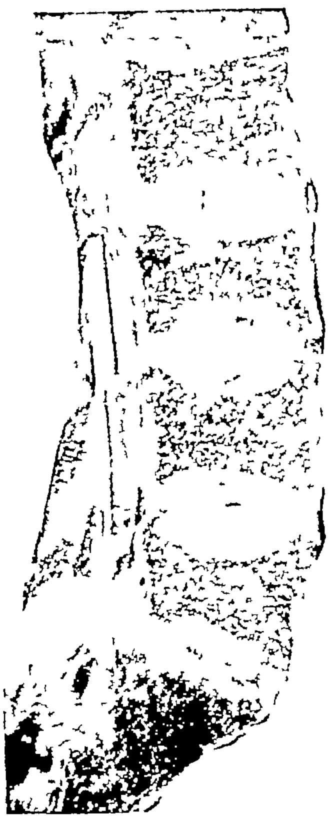


Fig 111 Slightly enlarged photograph of a fragment of dried bone from an aged woman Marked osteoporosis In comparison with the normal trabecular pattern (fig 23), the bone lamellae are reduced in thickness and in number and show numerous perforations



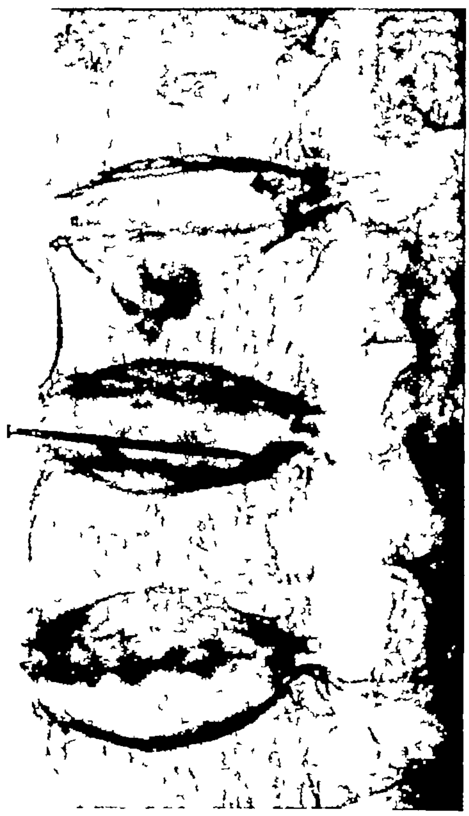


Fig 112 (left) Photograph of a sagittal section of the lumbar spine of a woman, age 59 Biconcave vertebrae produced by expansion of the discs Schmorl's node, L 3 The disc L 5—S 1 is of normal thickness

Fig 113 (right) Lateral radiograph of a sagittal section of the lumbar spine of a woman, age 82 The pin is in the D 12—L 1 space Marked osteoporosis with biconcave vertebrae Schmorl's node with bony shell in T 12

Osteoporosis of the vertebral arches develops parallel with the involvement of the vertebral bo but the forces exerted on the arches do not produce deformities comparable to those observed ı vertebral bodies The small joints adapt themselves readily to the deviations of the spinal caused by the vertebral osteoporosis

The changes just described constitute the clinical picture of senile osteoporosis, which first ap in the seventh decade of life The most important features are the appearance of biconcave verte wedging of the vertebral bodies and vertebral collapse Clinically, one finds no more than a weak of the back, and the occurrence of severe pain mands a search for some other cause This is in s contrast to the pain which is a regular featu presenile osteoporosis

Fig 118 (left) Lateral radiograph of the thoracic spine of a women, age 71 Marked osteoporosis with compres of several vertebrae with callus formation in the region of the vertebral plates Osteophyte formation

Fig 119 (right) Lateral radiograph of the thoracic spine of a man, age 77 Pin is in the T 6—T 7 disc Ma osteoporosis Collapse and wedging of T 7 and T 9 with condensation of the spongiosa

2. Presenile osteoporosis

In contrast to senile osteoporosis, which is very rarely accompanied by pain, there is form painful osteoporosis, involving, chiefly, the spine and pelvis, occurring usually in the sixth dec (Polgar) and called presenile osteoporosis It belongs to the group of hormonal osteoporosis and occurrence coincides with decreased production of androgens or estrogens (*fig 110*) Its frequenc greater in females and it is frequently called postmenopausal osteoporosis For Decourt, Gally (Guilleaumin, who obtained satisfactory results in its management with large doses of Vitamin the disease is an obscure form of osteomalacia Albright's investigations (p 61), Schupbach's perience, and the therapeutic results which we have obtained with hormone therapy, indicate t both sexes respond well to such treatment A test of such therapy may be the deciding factor

Fig 120 (upper left) Lateral radiograph of the thoracic spine of a woman, age 76 Pin is in the L 1—L 2 disc Marked osteoporosis with biconcave and cuneiform vertebrae

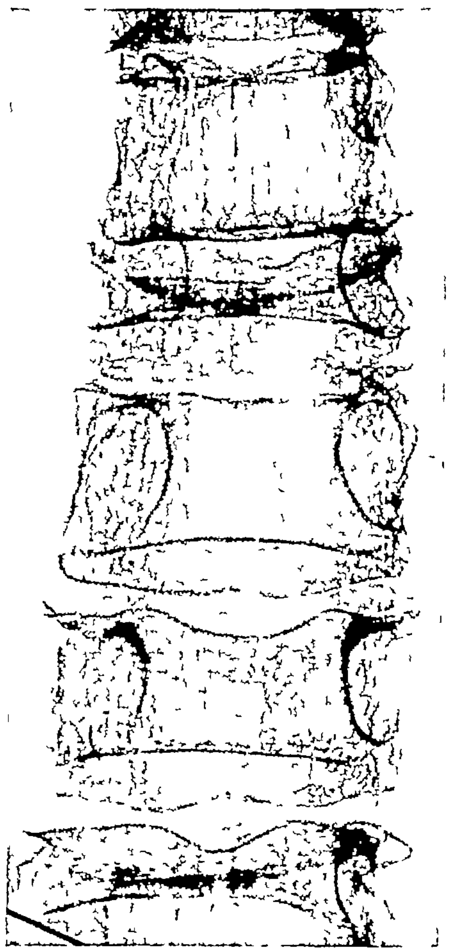


Fig 121 (upper right) Anteroposterior radiograph of the specimen in figure 120, after ablation of the vertebral arches

Fig 122 Photograph of the sagittal section of the spine of a man, age 69 Marked osteoporosis Brown degeneration and fragmentation of the discs Wedging of T 12 and L 3 and decrease in height of the other vertebrae No significant disc expansion

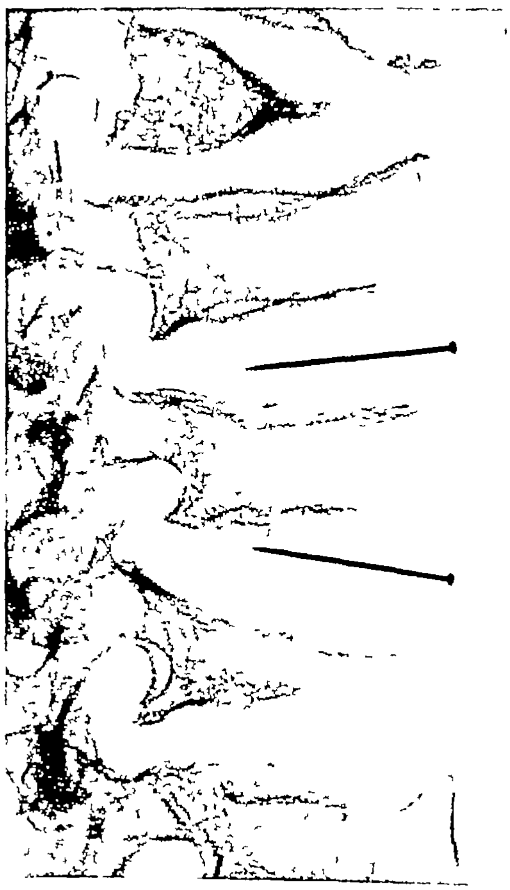


Fig 123 Radiograph of specimen in figure 122 Pin is in L 1—L 2 and L 2—L 3 discs

differential diagnosis, and one may thus give a definite answer to the medicolegal question of the role of trauma in the production of vertebral body collapse (Junghanns) Differentiation from Sudeck's atrophy is a complicating factor Merklen and Jacob have described cases which deteriorated steadily, resisting all forms of therapy

Fig 124 (left) Photograph of a sagittal section of the lumbar spine of a woman, age 77 Marked osteoporosis The vertebral bodies L 1 and L 3 are markedly flattened and slightly cuneiform in shape, with some resulting kyphosis No expansion because of degenerative changes

Fig 125 (right) Radiograph of specimen in figure 124 Focus of calcification in L 3—L 4 disc

Bibliographic references Burrows and Graham, Canigioni, Jesserer and Hörtnagel, Jesserer and Kirchmayr, Labhart and Schupbach, Lapayère, Lauber, Paltrinieri, Schmitt, Schüpbach and Courvoisier, Segre

3. Juvenile osteoporosis

Even as senile osteoporosis results from the physiologic decrease in hormone production, and as the precocious drop in the secretion of the antiosteoporotic hormone initiates hormonal osteoporosis, it is reasonable to assume that variations in hormone production at puberty may result in a disturbance of equilibrium which permits the adrenocortical hormones (S hormone) to inhibit the action of the osteoblasts (fig 110) The rare cases of osteoporosis observed in the young may be interpreted as being of this origin The disease is characterized by the presence of numerous biconcave vertebrae and by generalized platyspondylia (cf p 81) This is the "fish vertebrae disease" of Lindemann (Catel, Hammel, Hohmann)

4. Protein deficiency osteoporosis

The terminal phases of cachectic states are accompanied by bone atrophy and the changes in the spine resemble those of senile osteoporosis This form of osseous change is observed in the cachexia

Fig 126 (left) Photograph Sagittal section of the spine of an aged woman Osteomalacia The thoracolumbar vertebrae are slightly biconcave Cuneiform vertebrae and degeneration of the anterior segments of the discs have produced kyphosis (see senile kyphosis, figs 388—393)

Fig 127 (right) Radiograph of the specimen in figure 126 Cuneiform and biconcave vertebrae The fine granular and irregular structure of the spongiosa resembles Recklinghausen's osteodystrophy

of malignant disease and in long-standing tuberculosis, where it is seen in 50 per cent of cases (Liechti) Even the young may exhibit these changes

The primary cause of this condition appears to be a protein deficiency (proteins are essential components of the bone matrix), but we do not know whether protein deficiency alone can produce it The disturbance of hormone production which accompanies cachexia, very likely, plays a part of considerable importance Malnutrition and disturbances of metabolism are also concerned in the production of spinal osteoporosis, as has been observed with longstanding biliary fistulae (Diedrich) and in diseases of the liver (Mayer) Large doses of hormones and, possibly, the injudicious use of certain drugs may precipitate the appearance of this form of osteoporosis (chapter III A, p 61)

5. Rickets and osteomalacia

Although rickets is characterized by skeletal decalcification, the vertebral deformities of generalized osteoporosis (biconcave and wedge-shaped vertebrae) are rarely seen, and never to a significant degree The histologic lesions of the vertebrae are identical with those observed in other parts of the skeleton, but they are less pronounced in the long bones where growth is so much more rapid

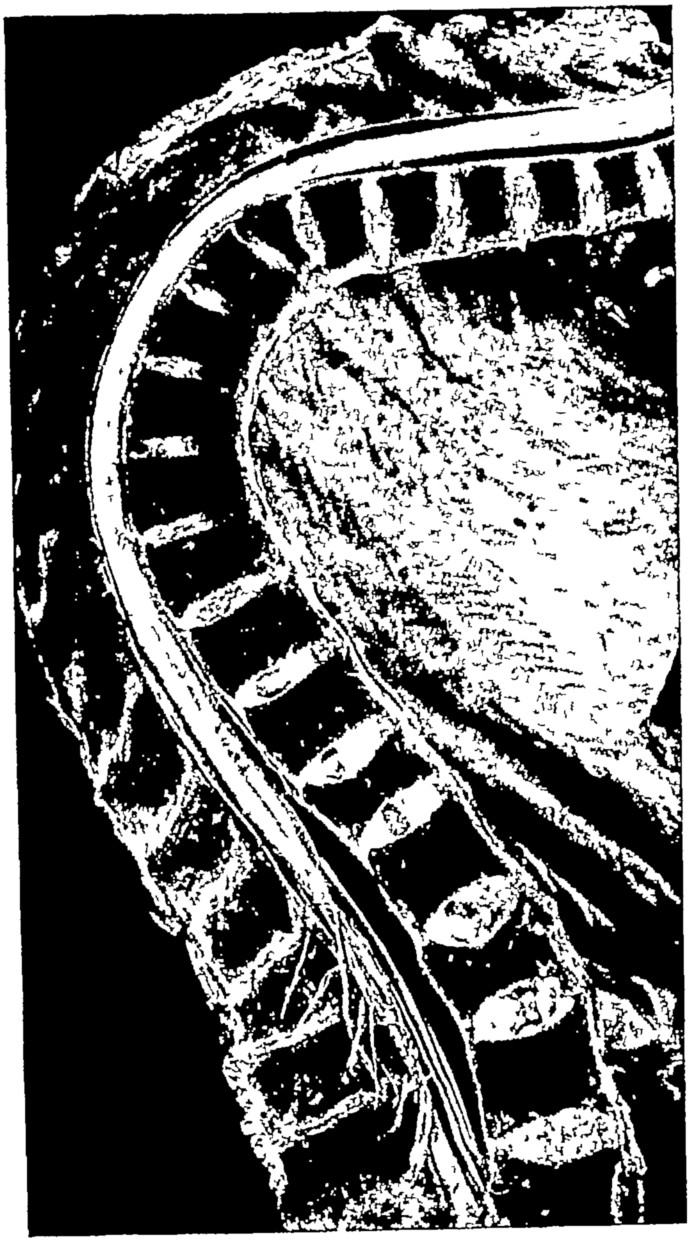


Fig 128 Photograph Sagittal section of the spine of an aged woman who died from starvation Biconcave vertebrae (lumbar area) and cuneiform vertebrae (thoracic spine) The discs in the midthoracic region show ossification of their anterior segments Senile kyphosis (see fig 393)

Nevertheless, the bony trabecular network may exhibit the same radiolucent linear striae seen in the long bones, if changes in the calcium content of the growing bone have followed either therapeutic measures or exacerbations of the disease process (Lyon, W Müller) Some writers report rachitic changes in the cartilage joining the vertebral bodies and arches, and believe these changes to be the cause of scoliosis in children (Schede) In the light of Schmorl's histologic studies, this hypothesis appears to be of very doubtful validity

In osteomalacia, the vertebral spongiosa is transformed by the production of osteoid tissue poor in calcium salts into a poorly organized osseous mass which on cross-section has a fine granular appearance (M B Schmidt) At first glance it is difficult to avoid confusion with Recklinghausen's disease (osteitis fibrosa cystica) and the radiographic findings contribute to this confusion (figs 126 and 127) At times, it may be difficult to differentiate from generalized Paget's disease (Schulze) The softening of the skeletal structures results in marked deformities of the spine, and of the thoracic cage and pelvis, resembling grossly those seen in osteoporosis (biconcave vertebrae, wedge-shaped vertebrae, platyspondylia, etc) The term "fish-vertebra" (biconcave vertebra) was used originally to describe the vertebral deformity of osteomalacia, as we have already pointed out The kyphosis of osteomalacia produced by the numerous wedge-shaped vertebrae may be marked and may even produce a gibbus deformity (Kreuzer)

The possible relationship between osteomalacia and presenile osteoporosis, and the transitional forms of these two diseases has been discussed previously Milkman's syndrome is quite analagous to osteomalacia, both conditions are characterized by marked osteoporosis of the spine, and apparently both diseases have a common etiology (Herold, Hopf, Lydin) The bone lesions of cadmium poisoning resemble, rather closely, those of osteomalacia (Lafitte and Gros)

6. The osteopathies of starvation and sprue

The vertebral lesions which are produced by severe malnutrition resemble those of senile osteoporosis (fig 128) Histologic study demonstrates intense osteoclastic activity and the changes of osteomalacia with osteoid formation (Gerth) Many writers have called this condition the "osteomalacia of starvation " All of the morphologic changes of osteomalacia may occur wedging, flattening of the vertebral bodies, biconcave vertebrae and marked kyphosis Such changes have been observed in the old and the young during the period of famine which followed the world wars (Dröse, Edelmann, Eisler and Haas, Girardier, Meulengracht, Porges, Seils, Wernly)

Both in infants (Heubner-Hertner's disease) and in adults (nontropical sprue) similar vertebral lesions occur, and probably this is also true in tropical sprue Protein deficiency with avitaminosis (Vitamin C) and the associated impaired calcium utilization interferes with the osteogenic process while the normal osteoclastic activity remains unchanged

7. Rare osteoporoses

Renal osteoporosis may occur during the course of numerous diseases of the kidneys and frequently in connection with hypertrophy of the parathyroids Its possible confusion with Recklinghausen's disease (see p 74) will be discussed later In the infant, the skeletal changes resemble those of rickets and the disease is commonly called "renal rickets" Marked disturbance of growth (renal dwarfism) may occur This form of osteoporosis may develop in adults with subacute glomerulonephritis and in numerous diseases associated with renal deficiency (Imhäuser, Uehlinger) With the exception of renal dwarfism, the chronic nephropathies do not affect the morphology of the spine

Meisels has described a "virile osteomalacia" as a feature of hyperthyroidism All prolonged states of hyperthyroidism are accompanied by osteoporotic changes (Uehlinger) but, in our experience, these rarely involve the spine

Endocrine disorders are also the cause of the rare Kaschin-Beck syndrome with which we have had no personal experience Platyspondylia, marked kyphosis, severe osteoporosis and destruction of the intervertebral discs are among the findings described (Bibliography see Liechti)

Vertebral osteoporosis is also a feature of Cushing's disease, or basophilic adenoma of the pituitary gland The vertebrae are flattened and are very markedly deformed (Askanazy, Cushing) The essential cause of these osteoporotic changes is, according to Albright, an increased production of an adrenocortical hormone (the S hormone, fig 110)

B. The osteodystrophies

1. Paget's disease (osteitis deformans)

The deforming osteodystrophy or osteitis deformans described by Paget is one of the group of dystrophies formerly known as osteitis fibrosa Its histologic appearance, which is unusually typical, is that of a complicated network of trabeculae which Schmorl called the "mosaic structure" and which he has described in detail (fig 129, Hallermann) Schmorl considered Paget's disease to be second in frequency only to osteoporosis and found it to be present in the skeletons of 3 per cent of all autopsy subjects (138 in 4603 autopsies) The disease is slightly more common in men over forty (3 5 per cent or 80 cases in 2268 autopsies) than in women of the same age group (2 5 per cent or 58 cases in 2355 autopsies) Study of the distribution of the lesions of Paget's disease among the components of the skeleton indicates that it is not the tibia which is most frequently involved, as

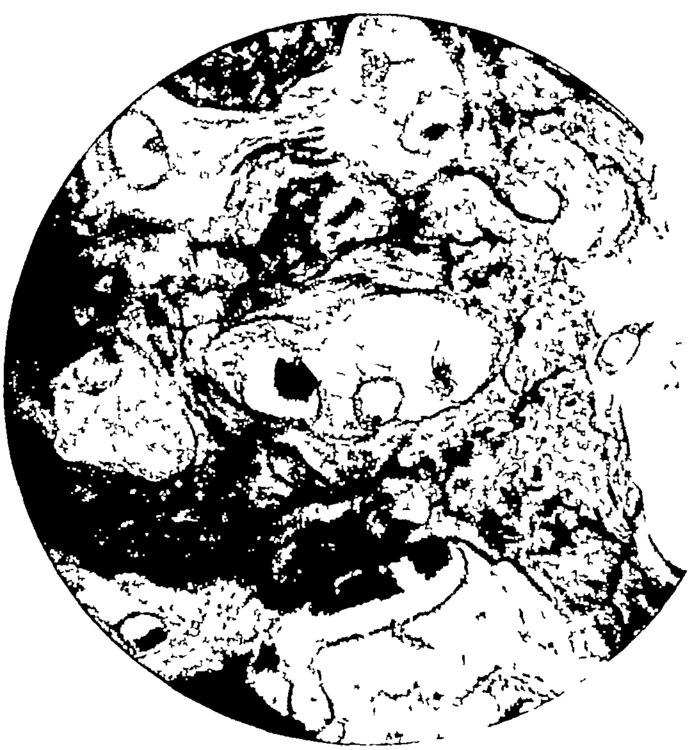
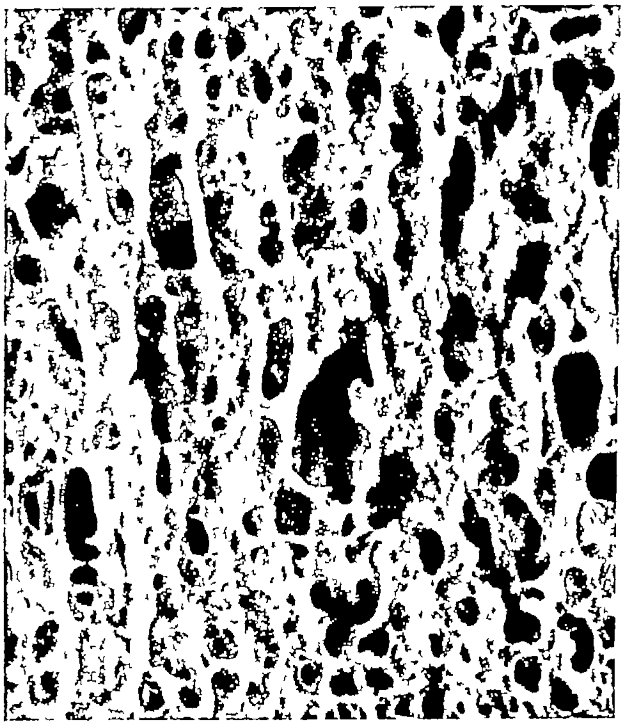


Fig 129 Microphotograph Section of a vertebral body showing osteitis deformans (Paget's disease) The trabeculae are thickened and their arrangement is distorted Marked "mosaic structure"

had been generally believed In fact, it ranks ninth in order of frequency and the sacrum (55 79 per cent) is the bone most frequently affected, with the vertebrae (50 per cent) second in order The order of frequency of involvement is the right femur (31 16 per cent), the skull (28 19 per cent), the sternum (23 19 per cent), the pelvis (21 73 per cent), the left femur (15 2 per cent), the clavicle 13 04 per cent), the ribs (7 25 per cent), the scapula (4 34 per cent) and the humerus (4 34 per cent)



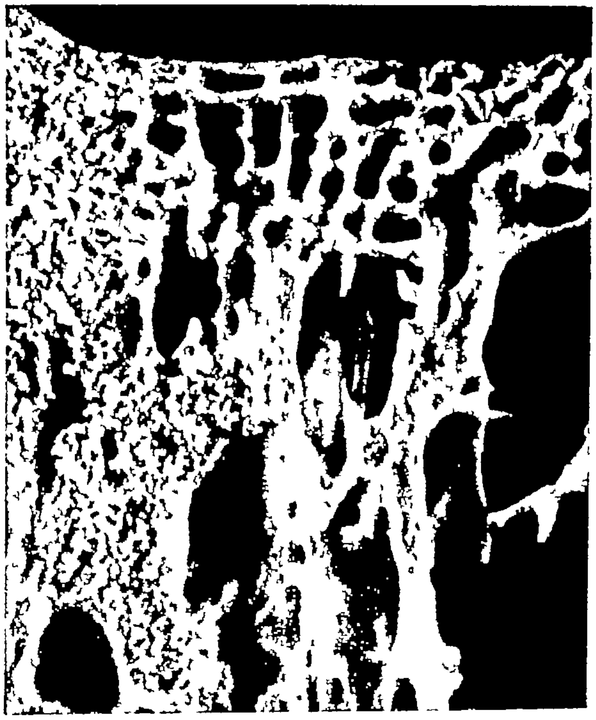


Fig 130 (left) Enlarged photograph of a macerated fragment of a lumbar vertebra Marked thickening of trabeculae (Paget's disease) (cf fig 23 showing a normal trabecular pattern)

Fig 131 (right) Enlarged photograph of a portion of a thoracic vertebra The coarse trabeculae of osteitis deformans are seen on the left Bone atrophy on the right

Osteitis deformans may involve one or several bones and, in rather rare instances, it may involve the entire skeleton Schmorl found the entire spine to be affected in 6 5 per cent of the cases of Paget's disease examined, while 50 per cent of them exhibited involvement of at least one or more vertebrae These findings offer a point of differentiation from osteitis fibrosa cystica (Recklinghausen's disease) which invariably affects the entire skeleton Here, an experienced observer will recognize changes in the architectural pattern of the bone where an area of Paget's disease exists These changes will be discussed later Frequently, the changes of osteitis deformans will extend from one vertebra to another by way of bridging osteophytes and, if fracture occurs in an involved vertebra, the callus formation will exhibit the architectural picture of Paget's disease (figs 134, 135 and 139)

Although the microscopic picture of Paget's disease is unvarying, the gross changes are subject to wide variations, familiarity with which is essential to radiologic differential diagnosis The involved bone is softened to such an extent that it may be cut with a knive, and the bone trabeculae are coarse and thick They may be packed tightly and compactly (fig 130) or may enclose empty spaces where rarefaction has occurred (figs 131 and 132) The first instance represents the so-called diffuse form, commonly seen involving the vertebral bodies and, in the dry specimen, resembling pumice stone Examination of the specimen and of the radiograph creates the impression of dense compact bone rather than of bone with a trabecular network, and for this reason the vertebrae of this type have been classified by some radiologists as "ivory vertebrae" (see p 86) or "marble bones" (figs 133, 140 and 141) Not infrequently, there is seen another form of vertebral Paget's disease, in which the process of absorption is predominant The bone trabeculae of the vertebral plates and the vertebral walls, subject to great static stress, are thickened and compressed, appearing

to surround the rarefied spongiosa with a compact mass, and these changes are equally demonstrable in the section and in the radiograph (figs 133, 135 and 136) Both variants may be present in the same spine (fig 141)

In spite of the accelerated rhythm of bone changes in osteitis deformans, the newly-formed bone trabeculae obey the general law of statics This is well shown in the zones of osteophyte production and particularly in deformed segments of the spine (figs 134 and 138) The relative malleability of the newly-formed osteoid in the spine of Paget's disease leads to deformities resembling those of osteoporosis, flattening, wedging and the formation of biconcave vertebral bodies (figs 133 and 136)

Fig 132 (left) Photograph of a sagittal section of a spine Macerated specimen Typical osteitis deformans Vertical trabeculae reinforcing the coarse trabecular structure Small cavities in the spongiosa

Fig 133 (right) Photograph of a sagittal section of two thoracic spines On the left is seen the typical "framework" appearance of osteitis deformans Diffuse changes on the right Increased anteroposterior diameter of one vertebra

Pathologic fractures may involve the spine in osteitis deformans, as well as other skeletal structures (Albrecht, Kienbock and Sereghi) The excessive volume of new bone may lead to compression of the spinal cord (Woytek), and Colclough has collected 30 such cases from the literature

The vertebral arches may show the changes of Paget's disease, either as solitary lesions or in association with changes in the vertebral bodies (figs 136 and 141) Sometimes, a vertebral body will exhibit the changes of osteitis deformans which are quite circumscribed and limited to one part of the vertebra The small osseous inclusions in an intervertebral disc, following degenerative disc changes, may be involved in Paget's disease when it is present elsewhere

There is a great diversity of opinion as to the etiology of osteitis deformans Many observations appear to support the theory that the disease is of inflammatory origin and among these we may mention histologic studies (Erdheim, Haslhofer, Rössle), the distribution of the lesions and the involvement of new-bone formation, *e g*, osteophyte formation and callus production The frequency of metaplastic change to malignant lesions (more than 10 per cent according to Chierici and

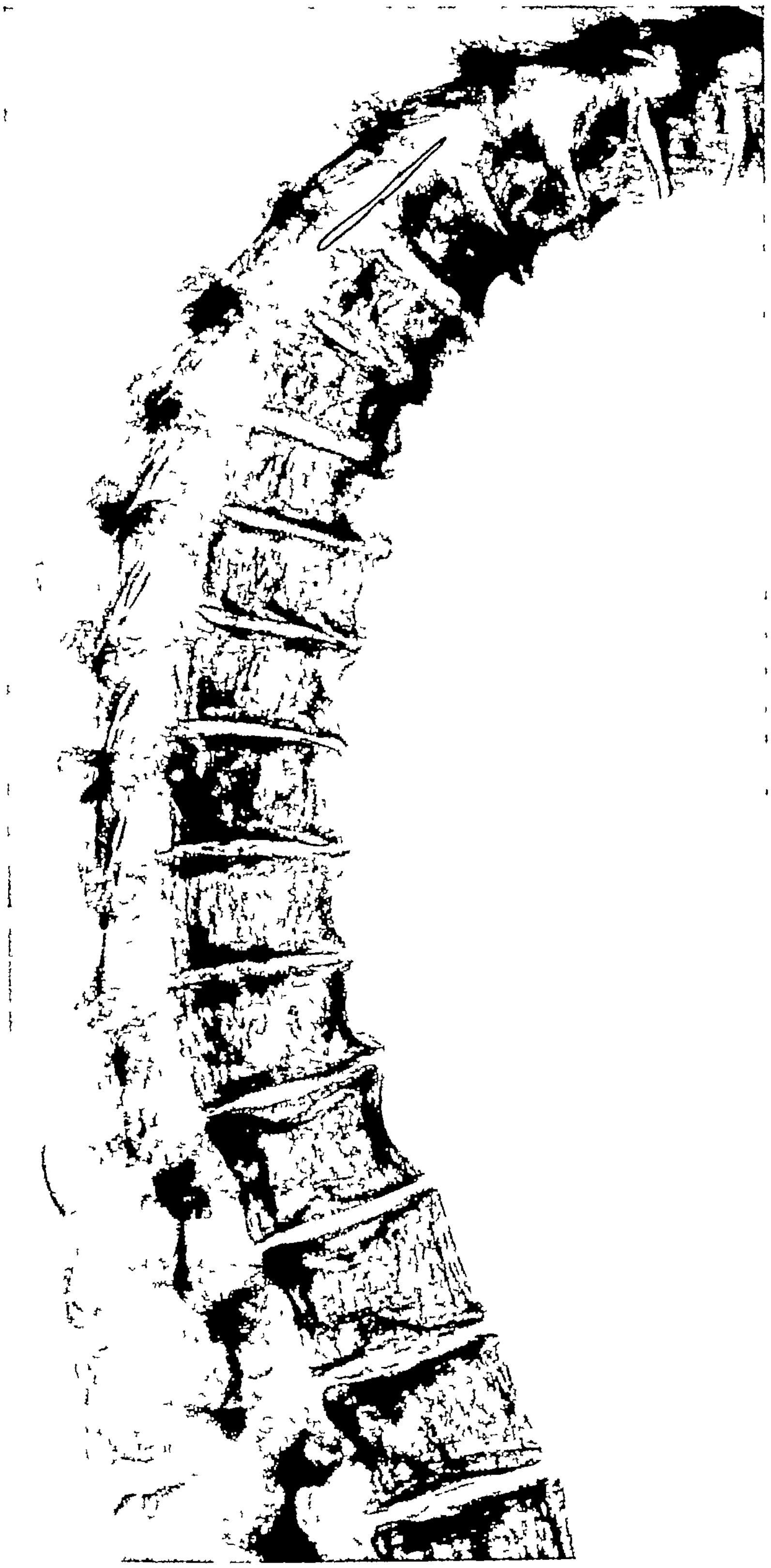


Fig 134 Lateral radiograph of a sagittal section of the spine Man, age 81 Typical osteitis deformans of all of the vertebrae including the osteophytes "Framework" appearance in some of the vertebrae

others) weighs somewhat against the theory of inflammatory origin Hellner and Poppe, however, classify Paget's disease among the true inflammatory processes

2. Osteitis fibrosa cystica (Recklinghausen's disease)

Recklinghausen's disease, or osteitis fibrosa cystica, is of much less frequent occurrence than Paget's disease and differs from it sharply by its involvement of the entire skeleton According to the great majority of writers (Berner, Dresser and Hampton, Gold, Hoffmeister, Hunter, Mandl, Oehlecker, Raynaud and Constantin, Simon, Snapper and Boevé et al), this generalized fibrous cystic osteitis is associated with parathyroid adenoma, the removal of which is followed by cure or, at least, arrest of the disease This is denied by other authors (Borchart, Jaurit, Vigano and others), but it must be remembered that the finding of a normal parathyroid does not exclude the possibility of parathyroid adenoma since they have been observed to occur within the thyroid or in other rather remote locations (Halshofer, Wachs et al)

Hanke, after reviewing the literature, raises the question of the role of metabolic changes with acidosis, comparable to those associated with parathyroid adenoma The characteristic features of the disease are a marked increase in the serum calcium and a moderate decrease in the serum phosphates Grossly the process is characterized by the appearance, of brown cystic tumors in various parts of the skeleton These changes were not present in 190 cases of osteitis deformans studied by Schmorl

The histologic picture of the bone marrow has many features analogous to osteitis deformans, but the absence of the "mosaic structure," the architecture of the spongiosa and of the cortex of the long bones (figs 142 and 143) permit differentiation of the two diseases (Schupp) In generalized osteitis fibrosa cystica, bone absorption throughout the skeleton, associated with areas of hemorrhage and with the presence of giant cells in the brown tumors is a prominent feature Deposits of new bone are observed at the site of fractures and infractions

Radiographically, the involved vertebrae are of low density and little contrast and may, if the intervertebral discs retain their elasticity, assume a biconcave form, usually not very marked (figs 144 and 145) In the thoracic spine the decreased strength of the spongiosa may permit collapse of the vertebral bodies, accentuating the thoracic kyphosis

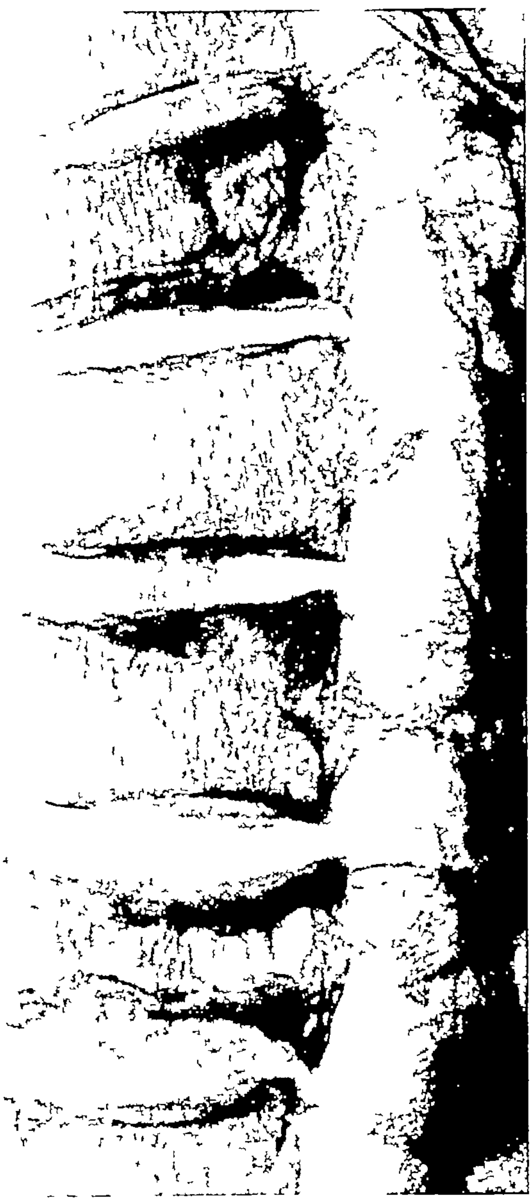


Fig 135 (left) Radiograph of a sagittal section of the lumbar spine Man, age 61 "Framework" appearance of Paget's disease, L 4 The vertebral arch and the osteophytes are involved in the disease process

Fig 136 (right) Lateral radiograph of a sagittal section of the lumbar spine Man, age 60 Osteitis deformans of two vertebrae, including their arches The upper vertebra (×) shows coarse trabeculae with vertical reinforcement The lower vertebra (× ×) shows marked condensation near its periphery ("framework" appearance) and there are small cavities in the spongiosa

3. Localized fibrous osteodystrophy

This condition, ordinarily encountered only in young adults, occurs as circumscribed cystic changes in the bones of the extremities and frequently is associated with spontaneous fractures Involvement of the spine is very rare, but when it occurs, the presence of cysts may lead to collapse of the affected vertebral body Cysts may be present in the vertebral arches, adding to their volume Characteristically, they contain a brownish-red fluid and, histologically, they resemble the brown tumors with giant cells which are seen in generalized osteitis fibrosa cystica

Thus far there is no rational classification of the osteodystrophies, and it remains impossible to group and to evaluate the cases thus far observed W Muller has described foci of "fibrous osteitis" in the vertebral bodies and arches of two young adults It would appear from the literature that

Fig 138 Photograph of a sagittal section of a macerated spine Osteitis deformans involves all of the vertebrae in the section Involvement of the osteophytes Coarse trabeculae in the posterior portions of the vertebral bodies and condensation of the spongiosa anteriorly

Fig 137 (left) Lateral radiograph of a sagittal section of the thoracic spine Man, age 82 Osteitis deformans of several vertebrae Block formation of five vertebrae with kyphosis Cause of block vertebrae formation undetermined Peripheral condensation in the remaining vertebrae Vertebral appendages involved

involvement of the vertebral arches is the more common (Adson, Fiorentini, Hellner, Henschen, Kinzel, Konjetzny, Madelung, Matolesy, Rebaudi, Ruggeri, Sick, Uiberall Wanke, Walz et al), but the lack of precision in the terminology must make one cautious in any attempt at exact evaluation Localized foci of osteodystrophy have frequently been mistaken for sarcomas (cf chapter III J 4, p 114) Hellner and Poppe believe that many cases of localized fibrous osteodystrophy were, in fact, cases of juvenile bone cysts, giant cell tumors and numerous other bone lesions

4. Fibrous dystrophy

A certain number of bone lesions occurring in the growth period and of unknown etiology have been grouped as fibrous dystrophy or fibrous dysplasia Uehlinger's table is of considerable assistance in the differentiation between this condition and other similar lesions The disease is, likely enough,

Fig 139 (upper left) Radiograph of a sagittal section of the lumbar spine Collapsed, biconcave vertebra (old fracture) Osteitis deformans Involvement of the vertebral arch The changes of osteitis deformans are seen in the callus

Fig 140 (upper right) Radiograph of a sagittal section of the lumbar spine Woman, age 76 Pin is in the L 1—L 2 disc Diffuse osteitis deformans of L 2, including its arch ("ivory vertebra")

Fig 141 (lower left) Lateral radiograph of a sagittal section of a macerated lumbar spine Woman, age 58 Osteitis deformans Peripheral condensation in L 3, L 4 and S 1 The diffuse type involves the other vertebrae L 1 is an "ivory vertebra"

Fig 142 (lower right) Enlarged photograph Fragment of a vertebra The bone trabeculae form a dense fine network with newly-formed bone decreasing the marrow spaces Osteitis fibrosa cystica Compare with normal bone (fig 23) and bone of osteitis deformans (figs 130 and 131)

Fig 143 (upper left) Photograph of a sagittal section of the spine Woman, age 52 Osteitis fibrosa cystica generalisata Obliteration of the trabecular pattern of the spongiosa Involvement of the vertebral body (indicated by the arrow) by small brown tumors (giant cell tumors), also seen in two vertebrae above

Fig 144 (upper right) Radiograph of specimen in figure 143. Fine granular appearance of the spongiosa Cf with the structureless pattern of Paget's disease

Fig 145 (lower left) Radiograph of the lumbar portion of the specimen in figure 144 Note fine granular structure Biconcave deformity and peripheral condensation

of endocrine origin If the changes are limited to the skeletal structures, it is known as Jaffe-Lichtenstein's disease, if it has associated skin lesions, it is called Albright's syndrome It appears to have some relationship to neurofibromatosis Bibliography Hellner, Liechti, Wachs and others

5. Sudeck's atrophy

The syndrome described by Sudeck, with its typical radiographic appearance of bone mottling, and with associated soft tissue changes in the extremities, is known by several names, *e g*, bone atrophy, dystrophy of the extremities, etc It has never been observed in the spine We believe, however, that even though histologic and radiographic evidence is lacking, its localization in the spine is quite possible, and it may be related to Kummell's disease or delayed post-traumatic collapse of a vertebral body (p 96) In future research it will be interesting to see whether the soft tissues adjacent to the spine (the spinal ligaments and the intervertebral discs) exhibit dystrophic changes as do the soft tissues of the extremities in Sudeck's syndrome Differential diagnosis between Sudeck's atrophy and osteoporosis is of great importance (Junghanns) Blumensaat, in his monograph on Sudeck's dystrophy concluded that this disorder was not demonstrable in the spine and that the delayed post-traumatic collapse of a vertebra (Kummell's disease) was nonexistent (chapter III G 4) The relation of narrowing of the intervertebral foramina to Sudeck's atrophy in the extremities is discussed in chapter III N

C. Various rare bone diseases

1. The lipoidoses: (xanthomatosis, lipoid granulomatosis)

Disturbances in lipid metabolism frequently manifest themselves in the skeletal structures (A W. Fischer, Lazarewa, Lyon, Pick et al), and involvement of the spine has been reported in Niemann-Pick's disease, Gaucher's disease and Hand-Schuller-Christian's disease) Gaucher's cells (reticulum cells with kerasin content) gradually replace bone and, eventually, may form a considerable part of a vertebral body Numerous infractions, even leading to complete collapse of the vertebral body, are not uncommon (Buxton, Junghagen, Pick, Schönbauer) These changes contrast sharply with Pott's disease in that no regenerative changes follow the destructive process The progressive rarefaction of the bone structures leads to changes resembling those seen in osteoporosis, *i e*, wedging, flattening, and biconcavity of the vertebral bodies Pick found numerous foci of necrosis and proliferation of granulation tissue in the bone marrow

Generalized xanthomatosis, or Hand-Schüller-Christian's disease (called lipoid granulomatosis by Chester), frequently produces quite extensive vertebral lesions, and the interplay of new bone formation and bone absorption leads to a quite characteristic appearance (figs 146 and 147) Wedge shaped and biconcave vertebrae are of frequent occurrence The lipoid cells (foam cells) are recognized readily in histologic sections (Schmorl,

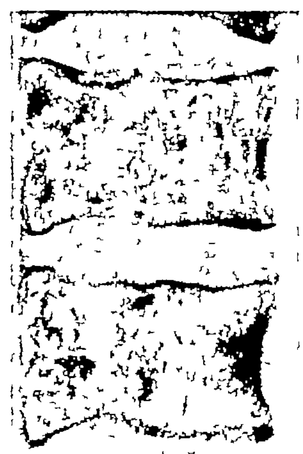


Fig 146 (left) Lateral radiograph of a thin section of the thoracic spine Areas of osteolysis, osteosclerosis and of lipoid granulomatous tissue producing multiple infractions

Fig 147 (right) Radiograph of a different section of the spine shown in figure 146

Chester) Paralysis, corresponding to section of the cord at a given level (Grünwald) also may occur For differential diagnosis see Hellner and Poppe

2. Osteopetrosis (Albers-Schonberg's disease)

This very rare generalized skeletal disease, the etiology of which is unknown, and described for the first time in 1904 by Albers-Schönberg, is associated with anemia and invariably involves the spine On cross section a vertebra appears to be a homogenous mass, grey-white in appearance, without bone marrow, and with no recognizable trabecular pattern (Dijkstra) The serum calcium is elevated (Schulze and others) Radiographically, the bone exhibits a uniform density with no trabecular pattern and, rarely, with decreased density in the central portion of the vertebral body (Glorieux, Kopylow and Remova, Lauterburg, W Müller et al) The lateral walls of the vertebral bodies appear constricted, and the vertebra takes the shape of a spool Marked fragility of the long bones is characteristic of Albers-Schönberg's disease, but it is not known whether the vertebral structures are equally fragile The histologic changes are much like those seen in osteitis deformans, and this similarity led Christeller to consider the two diseases as identical This is disputed by Schmorl and by M B Schmitt, who point out that osteopetrosis is, essentially, a disease of youth while osteitis deformans rarely, if ever, occurs before the age of 40 According to W Müller, fusion of the bony rims is delayed in patients with osteopetrosis, and this suggests the possibility of an endocrine factor in its etiology Hellner and Poppe believe osteopetrosis to be a hereditary disease, and Orel, studying a family group, thought it to be a recessive trait (Dijkstra, Pagenstecher)

The etiology of this disease remains very uncertain and its possible relationship to certain somewhat similar conditions (leukemic osteosclerosis, p 82, and "ivory vertebrae," p 86, etc) needs further investigation (Achenbach, Gerstel, Gortau, Harnapp) It is doubtful that the condensing osteitis described by Schwartz and Madaud is identical with osteopetrosis (chapter III O)

3. Osteopoikilosis

The small foci of condensation which are characteristic of osteopoikilosis may appear in the alae of the sacrum and in the articular processes and arches of the vertebrae, but are rarely seen in the vertebral bodies (Funstein and Kotschiew) Hence, we have omitted the details of this disease, which is also known as osteitis condensans generalizata and osteopathia condensans disseminata The histologic study of a single case of osteopoikilosis, without vertebral involvement, has been published by Schmorl Additional bibliography Haak, Marscherpa

4. Melorheostosis (Leri)

This rare disease (Uehlinger), until recently believed to be limited to the skeletal structures of the extremities, is a sclerosing type of hyperostosis which appears to "flow along the side of a bone" Involvement of the vertebral column was first described by Woytek and Lunedei, who observed in a man of 29 dense bone deposits developing along one side of the lumbar column Its etiology and its histologic features are unknown The disease is also known as "flowing hyperostosis"

5. Generalized hyperostosis

This disease, of unknown origin, involves the spine only in its later stages (Uehlinger) It is associated with pachydermia and, because of the osseous condensations which it produces, is sometimes known as acromegaloid osteosis It appears, usually, at puberty, seems to affect males only, and is characterized by marked thickening of the bone trabeculae, ossification of the ligaments and vertebral synostosis (block vertebrae)

6. Progressive myositis ossificans

Progressive myositis ossificans is described by Uehlinger as a hereditary disease leading, ultimately, to complete ankylosis of all of the [illegible] 'ations by ossification of muscle fibers and tendons The bony structures become osteopor[illegible] the spine assumes the "bamboo spine" appearance of Marie Strümpell's disease (p. 220'

7. Acromegaly and osteoarthropathy

In acromegaly resulting from the presence of an eosinophilic adenoma of the pituitary, the vertebral column may exhibit multiple changes Erdheim found an increase in the volume of the anterior portions of the vertebral bodies (acromegalic hyperostosis), and it is of interest to note that there is a like increase in the volume of the anterior portion of the disc space (Chester) Similar changes in the vertebrae have been observed in pulmonary hypertrophic osteoarthropathy (Chester)

8. Cretinism

The dwarfism of this disease represents the disturbance of skeletal development which results from hypothyroidism (thyroprival developmental disorders) Marked delay in the ossification of the bony rim and in its fusion with the vertebral body is followed by osteochondrotic changes in the intervertebral discs and the appearance of deforming alterations in the curvatures of the spine (Liechti)

D. The group of flat vertebrae (platyspondylia)

1. Chondrodystrophy; achondroplasia

Chondrodystrophy manifests itself in the vertebral bodies at birth by the cessation of development of the ossification centers The vertebral bodies are of reduced height and remain so during life and the resulting decrease in the length of the spine is as important in achondroplastic dwarfism as is the length of the long bones (Campbell, Donath and Vogl, Valentin, etc) Premature fusion of the vertebral body and the vertebral arch, due to faulty cartilage development, results in narrowing of the neural canal (Dietrich, Sumita) The achondroplastic dwarf exhibits marked deviations in the spinal curvatures, especially in the thoracolumbar region where an actual gibbus deformity may be present at the crest of the curvature (Dietrich, M Jansen, Marquardt), and the vertebral bodies are wedged and somewhat foreshortened anteroposteriorly (Dale, Drehmann, Hohmann, Swoboda, etc) Disc prolapse is of rather frequent occurrence in achondroplastic dwarfs (see p 145)

2. Generalized platyspondylia (vertebra plana)

This condition, described by Dreyfus, Lange, Nilsonne, Putti, Schrader, Wahren and Weil, is more or less related to chondrodystrophy of the spine It is characterized by generalized flattening of the vertebral bodies without diminution of the disc spaces The spine thus affected is shortened markedly and the contrast between the short spine and the normal extremities results in a striking disproportion Our present state of knowledge does not permit this condition to be classifed as a definite anatomical entity, but its frequent coincidence with other skeletal alterations speaks in favor of achondroplasia It is considered by some writers, therefore, as a chondrodystrophy of the vertebral column (Weil and others) Valentin suggests "osteochondropathia multiplex" as a suitable name, and W Muller describes it as "congenital vertebral dwarfism " The familial occurrence of this disease has been reported frequently (Dale, Morquio, Nilsonne, Ruggles, Volhard and v Drigalski) It has been observed only in young individuals, and we have no knowledge of its subsequent course (see Lindemann, "Fish vertebrae", p 68) Uncertainty as to the etiology of this condition and our lack of exact knowledge of its pathologicoanatomic aspects make an exact definition and satisfactory classification impossible (Beangen and Materi, Buchmann, Grudzinski, Marquardt, Marziani, Polgar, Nilsonne, Tavernier and Massias, Putti, Rost, Rota, Silverskiöld, Sturm, Thomsen, Uehlinger, Zubkov and Aronov, Yvin et al)

3. Osteogenesis imperfecta and osteopsathyrosis

Whether osteogenesis imperfecta congenita (Vrolik's d … and osteopsathyrosis (osteogenesis imperfecta tarda) or Lobstein's disease represent a sing … e or two separate entities is not known In the first type there seems to be a congenital lac … blastic activity possibly reflecting

a protein deficiency in the matrix (Hellner and Poppe). There is a marked decrease in the number of trabeculae in the cancellous bone, and the intervening spaces are filled with marrow containing much vacuolization (Dietrich). The decreased strength of vertebrae thus involved predisposes to fracture, although in the literature much more stress has been placed on fractures of the long bones with infrequent mention of vertebral fractures.

Osteogenesis imperfecta tarda (Lobstein's disease) is characterized by impairment of periosteal osteogenesis. The entire skeleton is poor in calcium content, and is very fragile. The vertebral changes are those of other atrophies: wedging, flattening and the formation of biconcave vertebrae (Chont, Zander) with various deformities and with cord lesions (Deutsch). The possible correlation between these conditions and pituitary dwarfism has been discussed by Lindemann and Lutterotti.

4. Vertebra plana (Calvé's disease)

The syndrome described by Calvé, and the subject of numerous articles in recent years (Sundt collected 21 cases and Hersel 32 cases) belongs to the group of flat vertebrae. It is, essentially, a radiologic syndrome and, as there are no histologicoanatomic descriptions of the disease, its classification is quite difficult. Mezzari studied histologically an infantile flat vertebra which showed changes of regeneration, and noted a focus of aseptic necrosis. Since the infant had hereditary syphilis, the writer's conclusions must be regarded with some skepticism. Mezzari's suggestion of "infantile pseudospondylitis" does not seem to be a very suitable designation.

The disease appears in children of from 2 to 12 years of age with the greatest incidence in those from 4 to 7. Its clinical features are pain, rigidity of the spine and gibbus deformities. A radiograph shows a sharp decrease in the height of one or several vertebral bodies which also may be widened (Willms). The bone trabeculae are rarefied and the rarefaction is not checked by complete rest (Sundt). Neither abscesses nor fistulae develop and healing occurs at puberty by bone regeneration and, sometimes, with restoration of the normal form of the vertebra without hyperostotic reactions in the adjacent vertebrae (Buhrig, Denks, Hersel, Lindström). It has been suspected that this condition is analogous to the diseases bearing the names of Osgood-Schlatter, Perthes, Köhler and Kienböck and the name "osteonecrotic flat vertebra" has been suggested. In the differential diagnosis, one must consider Kümmel's disease and vertebral fractures following minor trauma. Vertebral fracture resulting from muscle spasm may simulate Calvé's vertebra plana (p. 96). During the growth period, such a fracture may heal with restoration of normal contour (p. 96). Since so many cases of vertebra plana have a history of past trauma one is inclined to consider trauma as a possible etiologic factor. Mitchell has observed vertebra plana associated with a cyst in the neck of the femur. Pouyanne thinks that vertebra plana is not always the result of osteochondritis, but that many of them represent eosinophilic granulomata. Consequently, one should always search for changes in other bones. Janzen's report on the coincidence of nervous disorders and vertebra plana is of interest. (Additional bibliography: Buchman, Boorstein, Cebba, Federschmidt, Hanson, Harrenstein, Hess, Kuhlmann, Löhr, Matzner, Mezzari, W. Muller, Nagura, Panner, Polgar, Raszeja, Rosselet, Schrader, Stupnicki, Yaroschevski.)

E. Lesions of the spine in diseases of the hematopoietic and lymphatic systems and in the toxicoses

1. Bone changes in blood dyscrasias

In the adult, certain blood dyscrasias may provoke osteosclerosis to which Grieshammer has given the name "osteomyelosclerosis." They arise from a simultaneous disturbance of the hematopoietic and osteogenetic functions, which in turn results from disturbed mesenchymal differentiation of unknown origin (M. B. Schmidt). If this hypothesis is accepted, the question of the priority of the osseous lesion or the blood disorder loses its interest. Osteomyelosclerosis is characterized by condensation of the bony trabecular network, without any alteration in the contour of the involved bone. The sclerosis may be so dense as to give the appearance of osteopetrosis or "marble bones" (p. 80).

From the clinical standpoint, differentiation is not difficult since osteopetrosis is a congenital disease, while osteomyelosclerosis is an acquired disease of adults and is not associated with bone fragility Heilmeyer maintains that the two diseases are related, Albers-Schönberg's disease being the infantile type, while osteosclerotic anemia (osteomyelosclerosis, Heuck-Assmann) is an adult type He believes that disturbance in the differentiation of the primary reticulum cells is the common cause of both diseases Osteomyelosclerosis is seen in the following blood dyscrasias leukemia, aleukemic leukemia, anemia, polycythemia and erythroblastosis

While all parts of the skeleton are affected, the earliest changes usually appear in the spine and osteosclerotic changes are recognizable readily in the radiograph (fig 148) The condensation of bone is even more impressive in an anatomic specimen which shows a decrease in the bone marrow with the medullary space narrowed by osteoid tissue of slight radiopacity

Fig 148 Lateral radiograph of a sagittal section of the spine Leukemic osteosclerosis with preservation of the normal architecture

A rare variety of osteomyelosclerosis has been described by Apitz, who termed it tubular osteosclerosis Certain curious vertebral lesions, previously unknown and described first by Wienbeck (a single case), are called by him endangitic osteomyelosclerosis In these lesions, scattered sclerotic foci seen in the radiograph were, at first, believed to represent metastases On histologic study they proved to be areas of osteosclerosis surrounding blood vessels which exhibited changes resembling those of endarteritis obliterans (Bürger's disease)

Another bone change in blood disorders is osteolysis, a process characterized by relatively rapid bone absorption resembling that seen in acute spondylitis from which differentiation may be difficult (Melchior, Rolleston and Frankau and others) The scattered radiolucent areas seen in the radiograph are produced by proliferative activity in the bone marrow and they are seen in the leukemias and in sickle cell anemia Idelberger has described a condition characterized by generalized osteoporosis and decreased height of the vertebral bodies, and has called it "subleukemic lymphadenosis" Atrophy and sclerosis of the cancellous bone structure of a vertebra may be associated with various blood disorders and Patrassi has described such lesions associated with aleukemic lymphadenosis According to Baumann, a long-standing pernicious anemia may be accompanied by marked osteoporosis which results from disturbance of the absorbing function of the small intestine Bibliography Achenbach, Assmann, Brandau, Burkert, Hildebrand, Lyon, Trusen, Vogt and others

2. Hodgkin's disease

Following numerous isolated observations of bone lesions associated with Hodgkin's disease (Blount, Kuckuck, Joly, Hulten et al), the systematic studies carried out in Schmorl's Institute (Tetzner) established the frequency of vertebral involvement in this condition (see table 7, p 115) In 9 cases with skeletal changes, the spine was affected in 8, usually with changes in several vertebrae In 2 cases, foci of Hodgkin's disease were found in the bone marrow of all of the vertebrae with numerous areas of condensation present in the cancellous bone These were seen, radiographically, as ill-defined areas of osteosclerosis (fig 149) and their presence permits the radiologic diagnosis of Hodgkin's disease (Hellner and Poppe, de Sèze with Djian and Abdelmoula, Teschendorf, etc) These osteosclerotic lesions may be associated with foci of osteolysis leading to some degree of vertebral collapse (Beitzke, Hellner and Poppe, Hulten, Lassère and Poirier, Lyon, Possati, Reisner and Branda, Rosh, Stäudtner, Uehlinger, Wegener) Such collapse is seldom represented by wedging or by the formation of biconcave vertebrae, but usually by simple flattening The intervertebral discs usually remain intact, but the vertebral bodies and arches may be destroyed by the paravertebral lymph gland involvement (Hare and Lepper) Neurologic disorders may be associated

Fig 149 Lateral radiograph of a sagittal section of the spine Man, age 66 Pin is in the T 6—T 7 disc Hodgkin's disease, general osteosclerosis Note the mottling

with Hodgkin's disease (Bodechtel and Guizetti) After healing of the disease process, whether spontaneous or following radiation therapy, increased thickness and density of the trabecular network persists as a sequel

Bietzke has written a masterful description of Hodgkin's disease involving bone He considers it to be an infectious disease of the hematopoietic system, the lymph glands, the spleen and the bone marrow Others consider the disease as identical with reticulum cell sarcoma

3. Multiple myeloma (Kahler's disease)

Multiple myeloma is a rare generalized disease of the hematopoietic system (Hallermann, Lyon) Schmorl found it to be present in only 0 28 per cent of the autopsy subjects examined It produces osteolytic lacunae which coalesce as the disease progresses, and this osteolytic process, especially in the spine, is followed by disastrous results (figs 150—153) In the spine, the progressive course of the disease produces every type of spine deformity and vertebral fracture, and expansion of the intervertebral discs Usually, the arches and the processes are also affected, and pain is an early symptom (Hallermann, Spiller) Since the earliest detectable osteolytic lesions occur in the spine, radiographs of the vertebral column may permit diagnosis in a relatively early stage of the disease Collapse of numerous vertebral bodies, with resultant shortening of the trunk, decreases the height of the patient The vertebral collapse is often so complete as to reduce the height of a vertebral body to less than half of the height of the adjacent disc-space (fig 152) Differentiation from osteolytic metastases may be difficult, but generalized skeletal involvement is rare in metastatic malignancy, but the rule in multiple myeloma Myeloma, moreover, is never associated with reactive new-bone formation or osteosclerotic changes

Multiple myeloma is most common between the fourth and seventh decades, and is extremely rare in children (Rubinstein, Zäh) Although not every one is willing to class multiple myeloma as a malignant neoplasm, the tendency is to accept it as a member of the group of reticulum cell tumors The observation of a solitary myeloma has induced some writers to consider multiple myeloma as a rapid metastatic spread from a solitary primary focus, but this thesis is not supported by the previously described investigations carried out in Schmorl's Institute by Hallermann. Additional bibliography Abel, Davison and Balser, Rosselet and Decker, Santi, Simons

4. Toxic osteosclerosis

The toxins which are responsible for significant bone changes affect the hematopoietic system, and especially the bone marrow The most common and the most important of these are the fluorides which produce marked osteosclerosis, demonstrable radiographically, and affecting, principally, the

Fig 150

Photograph of a sagittal section of the macerated spine of an aged man Multiple myeloma Numerous osteolytic areas with collapse of several vertebral bodies

Fig 151 Lateral radiograph of a sagittal section of the thoracic spine Man, age 58 Multiple myeloma with areas of osteolysis Some of the vertebrae are well-preserved

Fig 152 (left) Lateral radiograph of a sagittal section of the spine Diffuse myelomatosis with varying degrees of collapse of several vertebrae

Fig 153 (right) Lateral radiograph of a sagittal section of the spine Male, age 51 Diffuse myelomatosis with vertebral collapse

spine and the pelvis Roholm has reported cases of fluoride poisoning, and Wilkie found that 40 per cent of persons working with cryolite (a sodium-aluminum fluoride) have osteosclerotic bone changes Poisoning by gold or radium may produce osteosclerosis, as may strontium and phosphorous poisoning, but the changes produced by the last two are rarely limited to the spine. Bibliography Achenbach, Klotz, Lehnerdt, Oehme, Phemister et al

F. Ivory vertebrae

Descriptions of ivory vertebrae are frequent in the radiologic literature, and there are those who would consider them as a disease entity The characteristic osteosclerosis of the vertebral body results in the radiographic image of a very dense vertebra, as is produced in all of the vertebrae in marble bone disease (p 80)

There are no anatomic or pathologic findings which justify the classification of "ivory vertebra" as a disease entity, and it reflects only osteosclerotic changes in the vertebral body produced by various etiologic factors Differential diagnosis of the various diseases which result in "ivory vertebra" may not be possible radiographically or by inspection of the anatomic specimen, but rests on histologic study

Among the various causes of "ivory vertebra," Paget's disease (osteitis deformans, p 77, fig 140) ranks first Others include infection, tuberculosis (Belle, Blonde and Keusiger, Crouzon, Delherme and Morel-Kahn, Giordano, etc), chronic infectious spondylitis and low grade osteomyelitis of the vertebral body Dubois-Trepagne has reported disappearance of the sclerosis and the re-establishment of a normal trabecular pattern and this seems to support the theory of an infectious origin Bone syphilis may be associated with "ivory vertebra" (Beitzke, Hahn and Deyke-Pascha, Souquez with Lafourcade and Terris, Worringer and others) and the osteosclerosis of Hodgkin's disease has been discussed on page 84

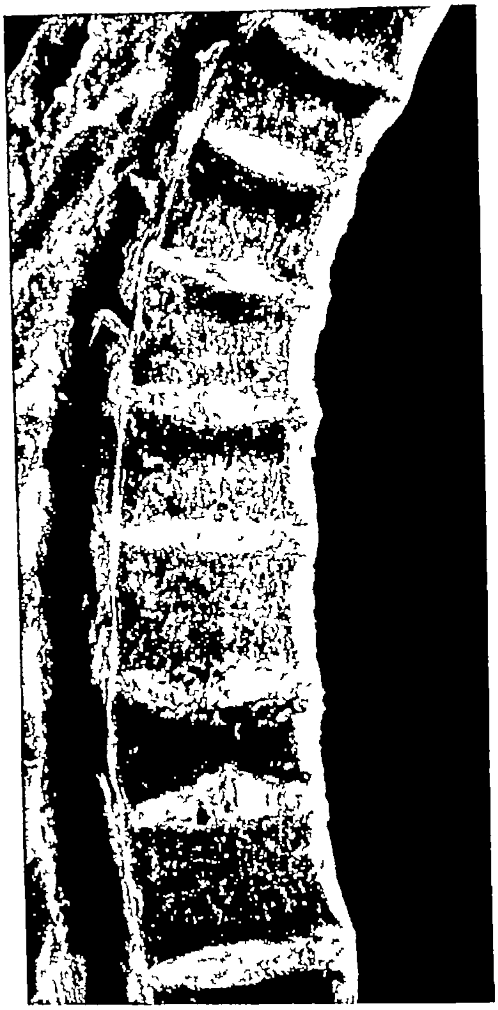
Many ivory vertebrae are the result of metastatic disease with associated osteosclerotic changes (Grilli, Nathan, Ochsner and Moser and others) Such changes may occur around osteolytic metastases in the vertebral bodies and, in a radiograph, assume the density of an ivory vertebra (Breitländer) These represent the so-called "osteoblastic metastases " Osteosclerosis may follow radiation therapy of malignant disease of a vertebra (Bársony and Schulhoff, Sicard), and primary sarcoma of a vertebra may assume the appearance of "ivory vertebra " It is apparent, then, that "ivory vertebra" is not a disease entity, but that it reflects the presence of osteosclerosis which may be of various origins, not always identifiable by radiographic study

G. Traumatic lesions of the vertebral body

1. Types and frequency of vertebral fractures and dislocations

Traumatic lesions of the spine are both interesting and important from the standpoint of diagnosis and of treatment Very frequently these injuries, and the occupational strains imposed on the spine, assume a very serious medicolegal aspect, and their evaluation demands complete familiarity with the radiographic manifestations of these changes Their treatment is the subject of a vast literature varying from the conservative (Magnus and associates, Bürkle de la Camp, Blencke, Bramann, Schleipen, Schwerdtfeger) to vigorous treatment which aims to reduce displacement and to restore the vertebral contours to normal (Böhler and his associates, Barbilian, Bazi, Becker, Breig, Bumm, Charbonnel, Davis, Dickson and Endy, Doerth, Felsenreich, Friedrich, Grinda, Heuritsch, Jimeno-Vidal, Jones, Kaspar, Kraus, Leser and Mayer, Mallett-Guy, Mathieu, Scheid, Schotte, Spamer, Vidal, Vorschütz, Watson, Werner et al) These diverse opinions are supported by clinical and pathologic material which will be discussed in a subsequent section Bibliography Adams, Burmeister, Dahl-Iversen, Decker, Doerth, Dunlop, Glorieux, Hall and Morley, Haumann, Heuritsch, Jewett, Julin, Janghanns, Karitzky, Laesecke, Landoff, M Lange, Lovasova, Martin, Michel with Mutel and Rousseaux, Pascher, Rostock, Ruge, Schmieden, Serra, Stock, Thomson, Wachs, Zeno

Statistics indicate that vertebral fractures are increasing in frequency (Aschan, Jaki, Jordan-Narath, Puschel, Rawls, Ruge, Wolf, and others) The most frequently involved region is the thoracolumbar area, with the cervicothoracic region as a poor second (Brack, Gaugele, Haumann, Magnus, Osgood, et al) Some observers have noted a greater frequency of occurrence in the cervical



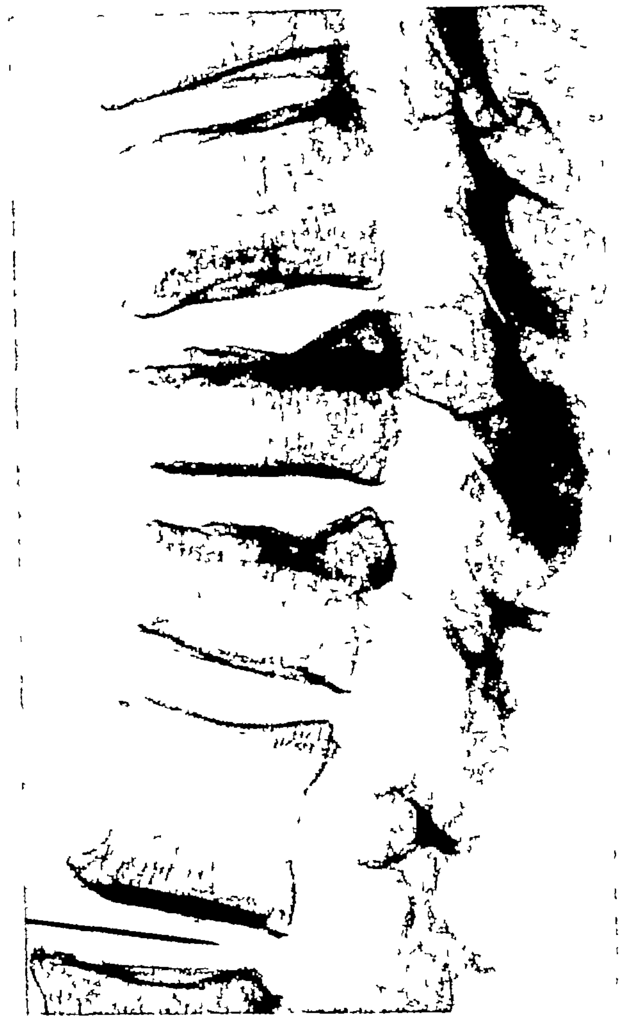


Fig 154 (left) Photograph Sagittal section of the thoracic spine Man, age 63 Compression fracture of T 9, with hemorrhage within the vertebral body Slight compression of the vertebral plates of T 4 and T 7 with hemorrhage

Fig 155 (right) Lateral radiograph of a sagittal section of the thoracic spine Man, age 80 The pin is in the L 1—L 2 disc Marked osteoporosis Old compression fractures involving the superior vertebral plates of T 10, T 11, and T 12 Wedging, and slight gibbus deformity Irregular contour of the discs in the involved area

column, although this is not in accord with general observation (Fumagalli, Robertson, Westermann and others) The clinical observations of Baumann, Burckhardt, Gulecke, Lob, Schneider, and Thorndike and the serial anatomic studies carried out in Schmorl's Institute indicate that fracture of several vertebral bodies is of rather frequent occurrence (figs 154—156) For this reason prudence demands a radiographic survey of the entire spine in spinal trauma since an unrecognized vertebral fracture will not only be untreated but when litigation is involved may be a serious medicolegal problem

Hellner found that of the patients with vertebral fractures seen by him, more than 15 per cent had multiple fractured vertebrae In Haumann's extensive statistical material almost one half of all cases of vertebral fracture had several vertebrae involved In Schmorl's collection, many spines showed two, three, or even more fractured vertebrae, sometimes at considerable distance from each other and with clinical recognition of only one fracture The severity of the fracture was not, however, equal in the several vertebrae His studies also disclosed healed vertebral fractures with no history of antecedent trauma Clinical experience indicates that vertebral fractures may occur, and heal, without

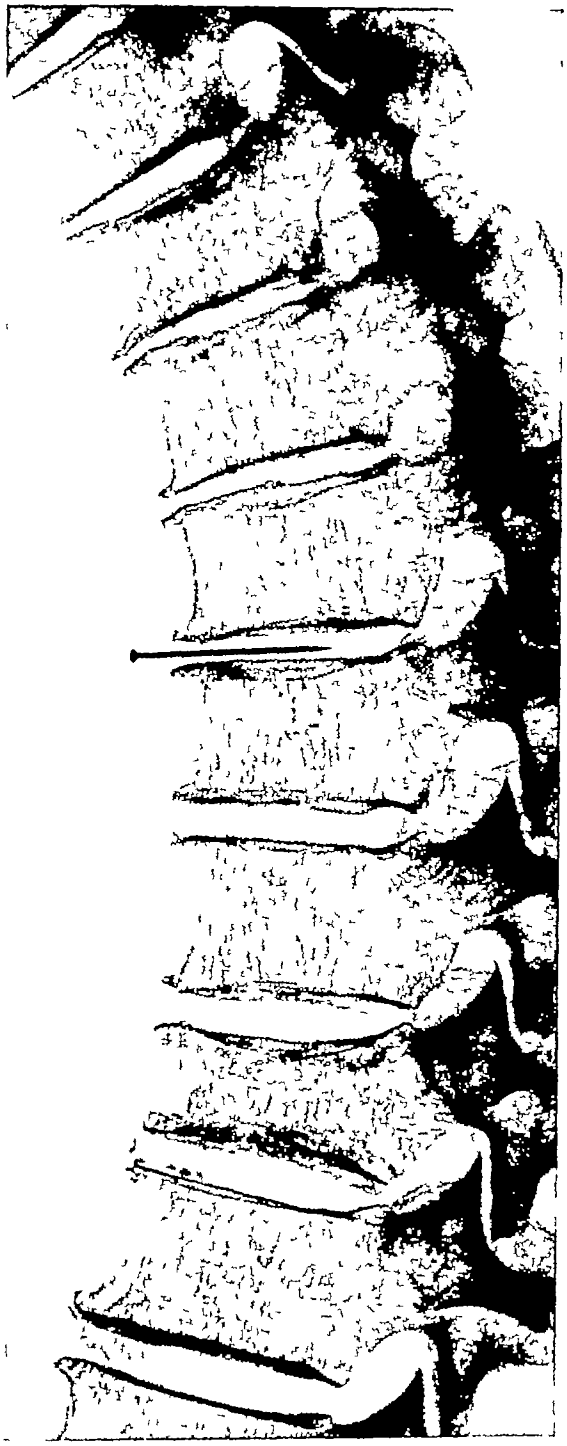


Fig 156 Sagittal section of the spine Man, middle age The pin is in the T 6—T 7 disc Compression fracture of T 9 with condensation of the spongiosa and with slight increase in the anteroposterior diameter of the vertebral body Depression of the superior vertebral plate of T 4, T 5, and T 7 with anterior displacement of a small fragment (with osteophyte) of T 7 Numerous degenerative changes (osteophytes)

any clinical manifestations (Hellner, Mutel, Putzu) A simple vertebral fracture, therefore, is considered by Schanz and others as a relatively unimportant injury It must be noted, however, that Schmieden has found that 20 per cent of vertebral body fractures result in death

Since the behavior of the intervertebral disc in vertebral body fractures is of great importance in the differentiation between tuberculosis and traumatic vertebral collapse, a detailed discussion will be found in chapter IV E

Compression of the vertebral body is the most common form of vertebral fracture It occurs most frequently in the thoracolumbar area and is an indirect fracture resulting from intolerable strain imposed on the vertebra in hyperflexion (figs 157—162) This is the mechanism which is operative when the subject falls from a height, is subjected to severe stress in the long axis of the body or when added stress is imposed with the body in flexion (*e g* , in the bent position of a miner) Such stresses can be produced by violent muscle spasm, as occurs in tetanus, or with some types of drugs (chapter III G 3) Under such circumstances the cancellous bone of the vertebral body is suddenly subjected to stresses which exceed the capacity of the bone, and compression fracture results Frequently, the anteroinferior margin of the vertebra immediately above indents the compressed vertebral body, producing anterior displacement of a small anterosuperior fragment (fig 159) Only occasionally does the vertebra below indent the compressed body above it Sometimes, one may see compression from above and below with forward displacement of a wedge-shaped fragment of the fractured vertebral body (fig 162) This is of more frequent occurrence in fractures with marked compression, and this type of fracture may result in the displacement of a large posterior fragment of the fractured vertebral body into the neural canal (figs 169—171) The resulting cord injury is a grave emergency frequently requiring immediate surgical intervention (Chrutchfield and Schultz, Titze and others)

Since compression fracture of a vertebral body produces wedging, with decreased height of the anterior portion of the body, sharp kyphoses may occur depending on the severity of the compression and the number of vertebrae involved Not infrequently, the observation of an acute kyphosis in a lateral radiographic projection will indicate the necessity of searching for a fractured vertebral body (Jaeger) An unusual direction of force may cause a compression fracture of a vertebra with lateral wedging, resulting in scoliosis rather than kyphosis Such fractures may be recognized in an anteroposterior radiograph by comparing the height of the injured vertebra with that of the superadjacent and subadjacent vertebral bodies (fig 160) This type of fractured vertebra has a considerable resemblance to the cuneiform vertebra of osteoporosis (fig 121) Vertebral compression

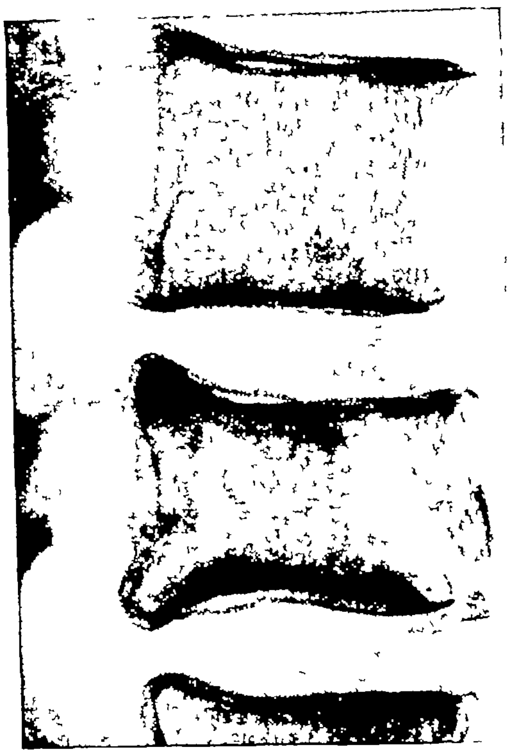


Fig 157 (upper left) Radiograph of a sagittal section of the spine Man, age 67 Recent comminuted fracture of L 2 with anterior displacement of fragments

Fig 158 (upper right) Lateral radiograph of a sagittal section of the spine Woman, age 65 Old compression fracture of T 12 with wedging

Fig 159 (lower left) Lateral radiograph of the spine Woman, age 54 Compression fracture of T 12 with anterior displacement of a fragment and with callus formation

Fig 160 (lower right) Anteroposterior radiograph of spine of subject shown in figure 159 Lateral spreading of T 12 and reduction in its height (see fig 121)

fractures with comminution show an increase in not only the anteroposterior, but in the lateral diameter of the vertebral body (fig 160), and this is an important observation in the differentiation from metastatic disease and inflammatory processes (Holfelder) In a recent compression fracture, the impaction of the cancellous bone effaces the pattern of the trabecular network, and the proponents of the conservative treatment believe that this is a representation of the most natural and the best method of splinting If the compression is reduced, and the normal contour of the vertebral body is

Fig 161 (left) Lateral radiograph of the thoracic spine Man, age 83 Compression fracture of T 12 with depression of the inferior vertebral plate and anterior displacement of a detached fragment Osteophytosis

Fig 162 (right) Lateral radiograph of the spine Woman, age 53 The pin is in the L 1—L 2 disc Old compression fracture of T 12 Triangular fragment fused with the antero-inferior amd anterosuperior margins of the adjacent vertebrae Narrowing of the T 11—T 12 disc space

restored, the lacunar spaces will be filled with blood, bone fragments and prolapsed disc tissue, and this leads Ettore to consider reduction of the compression as improper since it delays the healing process Wachs, examining a vertebra eight months after fracture, supports this opinion Scheidt, however, cites evidence to the contrary

Adjacent to a compression fracture there is seen frequently the shadow of a fusiform paravertebral mass which represents a hematoma and which resembles, somewhat, the "cold abscess" of Pott's disease (Eiselberg and Gold, Frangenheim, Strasser) It is observed most often in fractures of the thoracic vertebrae, and usually disappears in the course of a few weeks

The problem of callus formation in the healing of vertebral compression fractures is a controversial subject Schmorl has demonstrated, histologically, that endosteal callus formation occurs in the region of the compressed cancellous bone, and his observations are supported by Wachs's study of the stages of regeneration In the study of anatomic specimens obtained from jaundiced individuals with healing vertebral fractures, Schmorl observed bile pigmentation, visible grossly, in bone in the region of the fracture Since mature bone is incapable of absorbing bile pigments (although osteoid tissue may do so), this pigmented bone must represent callus formation In animal experimentation, Hoessly was able to demonstrate callus formation in vertebral fractures (W Block, Jaki, Lob, Stahl) It may be that the linear densities which are observed in radiographs of vertebral fractures of remote origin represent callus (fig 155), but perhaps they reflect only the impaction of cancellous bone structure Dyes has carried out serial radiographic studies during the healing of vertebral body fractures

Whether periosteal callus formation occurs in vertebral body fractures is debatable Certainly it is less prominent than in fractures of the long bones, but whether this results from the comparative immobility of the spine, or to a peculiar property of the anterior longitudinal ligament which serves as the periosteum of the vertebral body, is a matter on which we prefer not to speculate In any case, we have observed, repeatedly, old vertebral fractures with obvious periosteal callus which was demonstrable in a radiograph (fig 162) Studying such a callus in a macerated specimen, one gains the impression that it consists of small zones of ossification in the anterior longitudinal ligament, separated from the vertebral body and forming a coarse network over both the fractured and the adjacent vertebrae The possible role of trauma in the production of osteophytes in the region of the fracture cannot be etablished even by anatomical study The question will be answered only by serial radiographic studies, following trauma, in which the appearance and development of the osteophytes can be followed Their relationship to traumatic spondylosis deformans will be discussed in chapter V, p 196 (Ellner, Jaeger, Lob, Liechti, Scheidt, Scheidt and Prinz, Wachs and others, see also figs 163 and 164)

Fig 163 (left) Microphotograph of a section through an old fracture of a thoracic vertebra Endosteal callus with dense trabeculae (Specimen from the Museum of Pathology, The University of Berlin, Prof Rossler)

Fig 164 (right) Sagittal section of the spine of a woman, age 65 Old compression fractures of L 1 and L 3 fused by bone bridging between each fractured vertebra and that above it Moderate osteoporosis

Besides compression fractures there are other typical (although less common) vertebral fractures which have been classified according to various schemata, that of Kocher being the best-known Lob's classification, which recognizes the importance of the isolated disc lesion (first emphasized by Schmorl and his school) and satisfactorily correlates the morphologic changes and the clinical findings, seems, to us, the most useful In earlier classifications stress was laid only on the bone injury, and the significance of disc injuries was overlooked (see chap IV E)

Oblique fractures of the vertebral bodies differ from compression fractures by displacement rather than impaction of fragments and, because of involvement of the vertebral arches, they are often accompanied by moderate subluxation (fig 165) As a rule, the fracture line will pass from the posterosuperior to the antero-inferior surface of the vertebral body Usually, the upper one third of the vertebral body is affected, and fissuring of the intervertebral disc is invariable (fig 165)

Severe fracture dislocations, which are associated regularly with fracture of the vertebral arch, dislocation of the small joints, and rupture of the disc-ligamentous apparatus, may progress to satisfactory healing even without reduction of the dislocation This is true particularly in lateral dislocations, if the fragments are so dispersed that they are hardly in contact with each other, cord injury may not occur (fig 166) In such cases, healing by callus, and restoration of certain functional capacity is possible Such cases have been reported in the clinical literature by Avellan, Baumecker, Brailsford, Hanke, Horsch, Kanert, Lawson, Matti and Sabin Forward dislocations are always associated with grave cord injuries (Sabin)

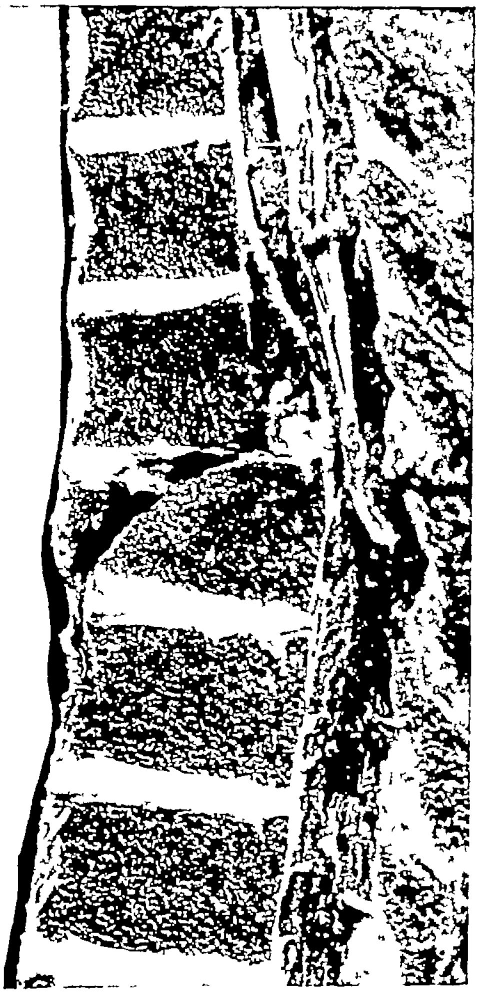


Fig 165 (left) Photograph Sagittal section of the thoracic spine Man, age 24 Oblique fracture of T 8 with extensive destruction of the T 7—T 8 disc and with slight anterior dislocation of the spine above the fractured vertebra A hematoma beneath the posterior longitudinal ligament elevates the disc fragments

Fig 166 (right) Radiograph of the thoracolumbar spine of a young girl Transverse fracture of L 1 with lateral displacement of the upper fragment and the spine above it The displacement equals the entire width of the vertebral column Section of cord with complete paralysis

Transverse fractures with posterior separation of the fragments are extremely rare They are produced by a force which represents a combination of traction and hyperflexion, accompanied by injuries of the small joints and the vertebral arches Eiselsberg and Gold first described such a fracture involving the first lumbar vertebra, and a similar injury of the third lumbar vertebra was observed by Deuticke Transverse fractures produced by hyperextension and with the anterior separation of the fragments are also rare, and the mechanism which produces them commonly results in rupture of the aorta and the vena cava (Faulwetter, Schum et al)

Sagittal fractures of the cervical vertebra associated with fractures of the vertebral arches and cord damage have been described by Blumensaat (Bourmer, Justus, Stimpfl and others)

The cervical column is the most common site of dislocations and fracture dislocation of the spine (Andersen and Loughlen, Baumecker, Galli, Farkas, Hanke, Jaski, Grinda, Stahl, Zitka, Coults, Grevillius and Ingelmark, Knoflach, Eickenbary and Le Cocq, Polony, Pommé and Narcot, Mackh, Schnyder, Towne, Warshaw, Wenzel) The uppermost cervical vertebrae are the most vulnerable, and serious injury may follow rather insignificant trauma as, for example, in diving (Dörffel, Jefferson, Sommer, Kulenkampff et al) Friedmann and Tibe have classified dislocations of the atlas in three categories (1) lateral dislocation, (2) torsion dislocation (right or left) and (3) anterior dislocation

Fig 167 (left) Photograph Sagittal section of the spine Man, age 37 Fractures of T 3 and T 4 with cord compression by posteriorly displaced fragments Large defect following laminectomy (Specimen in the Museum of Pathology, The University of Berlin, Professor Rossle)

Fig 168 (center) Photograph of a sagittal section of the lumbar spine Old compression fracture of L 4 with posterior displacement (into the neural canal) of a large fragment and anterior displacement of a smaller fragment

Fig 169 (right) Photograph of a sagittal section of the lumbar spine Old compression fracture of L 4 with displacement of a large fragment into the neural canal Anterior displacement of a small fragment

Langworthy has observed 17 bilateral and 19 unilateral cervical dislocations Dislocation and fracture-dislocation of the cervical spine may occur without cord damage as previously described (Eiselsberg, Schloffer, Caraven) Additional forward displacement as a late complication in a well-tolerated vertebral dislocation may produce cord symptoms and findings which require surgical intervention (Courcaud, Schmieden, Tavernier) Feigel has described a quite unusual case in which dislocation of the fourth thoracic vertebra with section of the cord occurred during an obstetric maneuver

The lumbosacral area is another site of predilection for dislocation and fracture-dislocation of the vertebrae Brocher has described posterior displacement of the fifth lumbar vertebra caused by a single trauma (chapter VIII C) Tilting of the pelvis and lumbosacial dislocation is described in the clinical literature (Bado, Lippens, Lombard and Solal, and others) These dislocations and fracture dislocations must not be confused with spondylolisthesis which will be discussed in chapter VIII (cf fig 67) The role of the small vertebral joints in vertebral dislocations is described in chapter III H 4

Fracture-dislocation of the odontoid process deserves special discussion It is produced in hyperflexion of the head with resultant compression fracture or detachment of the process (Manfredi) Accompanying cord injury is common, even with proper treatment bony union rarely occurs, and the anatomic specimen will exhibit a pseudoarticulation A poor blood supply seems to be responsible for the nonunion (Ellermann) Bibliography J Böhler, Brunner, Brussatis and Müller, Magnantl, Munz, Osgood and Lund, Ruge, Wurmig

Fractures of the sacrum which, formerly, have excited but little interest have been described more frequently in recent years Transverse and oblique fractures of the third sacral segment are the most common They may, however, be vertical, traversing the sacral foramina or the alae of the

Fig 170 (left) Lateral radiograph of the lumbar spine Man, age 39 Compression fracture with considerable narrowing of the intervertebral foramina

Fig 171 (right) Lateral radiograph of a sagittal section of the spine of a woman, age 80 Old compression fracture of L 3 with vertebral body displacement which produced posterior projection of the posterosuperior margin of the vertebra (compressing the neural canal) while the antero-inferior margin projects forward Central Schmorl's node

sacrum They are, almost always, associated with fractures of the pelvis, and visceral injuries are of frequent occurrence (Ruge, Salotti, Rush, Guillot)

Fractures of the coccyx, with significant displacement of fragments (usually forward), present great diagnostic difficulties because of the numerous and varied anomalies of the coccygeal segments Nerve compression and pressure of fragments on the rectum may cause considerable pain and discomfort Fractures of the pelvis are sometimes accompanied (6 per cent) by coccygeal fractures (Angerer, Becker, Drueck, Krauss, Ruge)

Spinal cord involvement in vertebral injuries depends on the site and the type of fracture, dislocation or fracture-dislocation, as we have mentioned previously (figs 167—171) There are varying estimates of the frequency of occurrence of cord damage 50 per cent according to Boorstein, 18 to 36 per cent according to Wainstein and 16 2 per cent, if Lob's estimate is accepted In general, somewhat more than 15 per cent of vertebral fractures result in paralysis (Magnus, Ruge), either from pressure by a bone fragment or by a hematoma, or by partial or complete section of the cord

Glorieux and Guttmann have given a quite detailed account of these lesions The gravity of the prognosis depends almost entirely on the extent of the cord injury The formation of renal calculi may constitute a secondary complication (Annovazzi) The persistence or the aggravation of neurologic symptoms demands surgical intervention Bibliography J Böhler, Bruhl, Burmeister, Crouzon, Craig, Deuticke, Enderlen, Hudson, Th Kocher, Kunz and Böhler, Lorenzo, Nicholl, Oehlecker, Schmieden, Schlachtezki, de Quervain, Vernengo, Vukovich et al

2. Vertebral fractures following minor trauma

Recent observations have shown that vertebral fractures are not necessarily the result only of violent trauma but that, at times, a rather insignificant accident may cause collapse of a quite healthy vertebra Vertical motion of the body in a moving automobile (Weiss), children's games (Mull), simple gymnastic exercises (Hellner), minor traffic accidents (Schneider), sudden motions of the head (Hammond), the torsional strain of discus throwing (Dahl), diving (Umlauft) and numerous other slight traumas may sometimes be sufficient to cause a vertebral fracture (Jäger, Deckner, Ruge, Püschel) The uncoordinated contraction of various groups of back muscles with resulting paradoxic fixation and rotation of certain segments of the spine appears to be the mechanism responsible for the production of many vertebral fractures Frequently, pain and other neurologic symptoms appear some time after the trauma perhaps because of the detachment of an impacted fragment (Curat) or the gradual development of a hematoma

These fractures, occasioned in normal vertebrae by minor traumas, must be differentiated from pathologic fractures These latter occur in osteoporoses of various origins (including effects of medications, such as steroids), and in other pathologic changes involving bone (Curtiss with Clark and Herndon, see chapter III A)

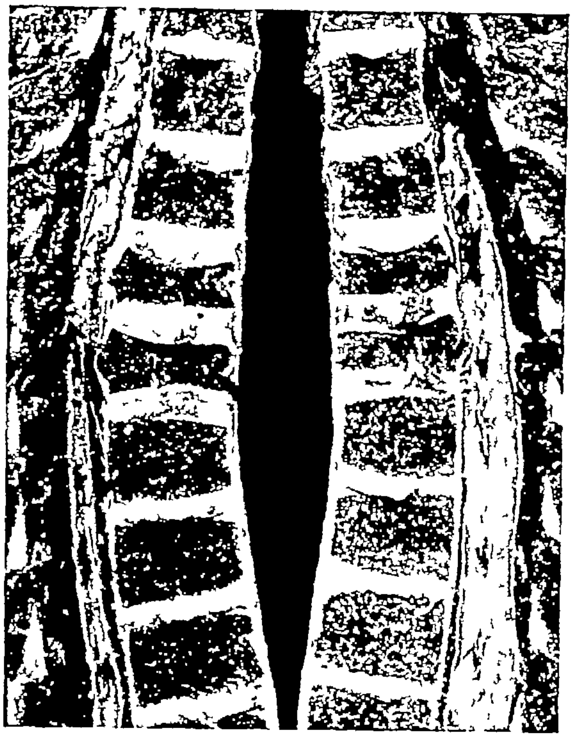
3. Vertebral fractures produced by muscle spasm

The experience of recent years has demonstrated the possibility of vertebral fractures resulting from violent muscle spasm (fig 172), and there is a series of histologic studies of vertebral fractures caused by the spasms of tetanus (Bäcker, Egerstadt, and several cases in the collection of Schmorl) The long-disputed question as to whether a healthy vertebra can be fractured by muscle spasm has been answered in the affirmative Erlacher, Magnus, Spieth, and others have denied this possibility, but vertebral fracture by body rotation, etc , as discussed above, speaks in favor of the importance of muscle spasm as an etiologic factor

Vertebral fractures from muscle spasm were first observed in tetanus (Bäcker, Chasin, Erlacher, Pusch, Scharsich, Zuckschwerdt), and subsequently were reported with spasm of other origin Modern shock therapy has played an important part, quite capable of producing vertebral fractures (Bösch, F Lord, Sonnenschein, Androp, Carp, Dedichen, Fromme and Wachs, Reed and Dancey, Vogt and others) The muscle spasm which accompanies an epileptic seizure may also cause fractures (Androp, Blair), but these must be rather rare, since Carp found no evidence of vertebral fracture in 7,500 cases of epileptic seizures However, quite the contrary was observed by Moore, Winkelmann and Solis-Cohar, who reported vertebral fractures occurring in 90 per cent of severe epileptic seizures Kjelland has reported a vertebral fracture occurring in a case of puerperal eclampsia

Fractures due to muscle spasm are most frequent at the crest of the normal thoracic kyphosis and frequently involve several adjacent vertebrae Usually, they occur between the fourth and the eighth thoracic segments and are seen only occasionally in other regions of the spine (Androp, Brunzel, Guntz, Vogt et al) Quite often they are associated with other skeletal fractures and dislocations, notably the transverse processes, the femoral neck, and the humerus (Androp, Carp, Chasin et al) Fractures resulting from shock therapy are more frequent (20 to 45 per cent) than those caused by tetanus They are of greater frequency in men than in women, probably because of the greater muscular development of men Clinical observation indicates that fracture occurs mostly in the course of the first treatments in convulsive therapy (Faurbye and Poort) The fractured

vertebra usually exhibits anterior wedging and lateral spread In adolescents, such fractured vertebral bodies may, in time, regain their normal contour as does the vertebra plana of Calvé (see p 82, Zuckschwerdt and Axtmann) Figure 173 (schema of Güntz) illustrates the action of the muscular forces which produce fracture by forced flexion of the midportion of the thoracic spine Krause



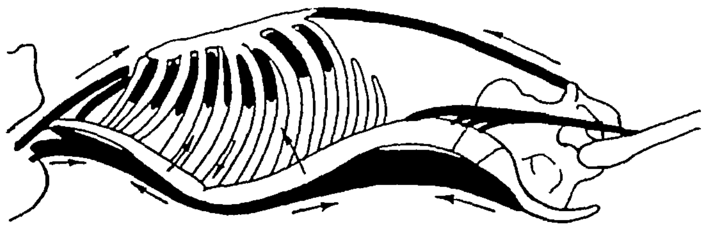


Fig 173 Diagram (Guntz) illustrating the muscular forces which act on the spine Flexion of the spine results from the contraction of the large group of flexors between the poles of the body The powerful extensors of the back maintain the cervical and lumbar lordotic curves Thus, sudden violent muscle contractions produce fractures of the thoracic vertebrae

Fig 172 (left) Photograph of a sagittal section of the thoracic spine of a child Compression fractures of two thoracic vertebrae as the result of a tetanic convulsion

and Langsam have emphasized the lordosis-producing action of the lumbar extensor muscles and the kyphosis-producing action of the abdominal flexors, and their role in the production of vertebral fractures of muscular origin According to certain recent publications these fractures are to be considered as fatigue fractures resulting from prolonged clonic and tonic muscular contractions (Fromme and Wachs, Krause and Langsam, experiments with electric impulses of Göcke) Literature Axdrad, Becker, Buber, Borchard, Clarenz, Faldini, Follmer, Friedrich, Junghanns, Kamniker, Leube, Liechti, Mertens and Bader, Mikula, Nagy, Ode, Pokorny, Portmann, Pusch, Reddingius, Roberg, Rychlik, Sauser-Hall, and Wilhelm

4. Delayed post-traumatic vertebral collapse (Kummell's disease)

The first publication by Kümmell (1891) on delayed post-traumatic vertebral collapse stimulated the publication of numerous articles in the German and the French literature (In the French literature, the lesion is known as "Kümmell-Verneuil's syndrome," or as "traumatic spondylitis" or "traumatic spondylosis " Kümmell described the syndrome as, "a relatively insignificant spinal trauma, the symptoms of which disappear often within a few days but which, after several symptom-free months manifests itself by discrete back pain, by the appearance of vertebral rarefaction, and by gradual collapse of the vertebral body with a resulting 'gibbus' deformity Suppuration, as in Pott's disease, bone condensation, as in syphilis, or osteophyte formation, as in spondylosis deformans, never occur "

Schmorl observed several such cases in his Institute in Dresden and reported them to the Orthopedic Congress in 1926 He found the anatomic features of these cases to be those described by Kümmell, with complete destruction of the cancellous bone, vertebral collapse and a gibbus deformity (fig 174) There was no microscopic evidence of callus formation or inflammation, and there was nothing to suggest an infectious process, although according to Kümmell infection may occur as a complication Heiligenthal found evidence of tuberculosis in a case which Kümmel had classified as "post-traumatic vertebral collapse" and thereupon rejected the concept of Kümmell's disease as

an entity, although in this particular case Kummell regarded the tuberculous process as secondary to the primary vertebral collapse

Among the possible etiologic factors, we may cite impaired nutrition of the involved vertebra (Buchert, Schmorl), hyperemia and hemorrhage (Lériche, Roederer), vasomotor disturbances (Tréves), neurologic disorders (Silhol), disturbance of callus formation by too early weight-bearing (Stahl, Matti), overlong bedrest (Juillard), traumatic spondylitis (de Quervain), traumatic necrosis (Gold) and fatigue fracture (Mutschler) Among 44 cases of spinal trauma without initial demonstrable vertebral lesions, Roeder found 7 with delayed vertebral collapse (Kummell's disease) Considering that patients with back pain commonly have some history of trauma, and that Schmorl, in his autopsy studies, frequently found previously unrecognized vertebral fractures, some writers have rejected the hypothesis of Kummell's disease as an entity and consider the syndrome to represent an unrecognized or untreated vertebral fracture (Blumensaat, Froelich and Mouchet, Gaugele, Haumann, Hosford, Imbert, Jordan, Magnus, W Müller, Schmieden, Sorrel and others) On the basis of his histologic studies, Kux considers microscopic traumatic lesions to be the principal etiologic factor in the production of delayed vertebral collapse, and Nicolini and Pittaluga observed necrotic foci in the cancellous bone of the collapsed vertebra Putti considers the condition to represent nonunion following a vertebral fracture and sees no reason to classify it as a separate entity, Lob, after pathologicoanatomic studies believes it to represent only a variant of vertebral fracture characterized by necrosis of cancellous bone and insufficient new-bone formation He also found concurrent disc injuries (cf p 178) The literature indicates that there is not always involvement of a single vertebra, but that several vertebrae adjacent or even widely separated may be affected (Helly, Petridis et al) Rigler has reported a case of a 54 year old woman, whose radiographs shortly after injury showed fractures of the fifth cervical and the twelfth thoracic vertebrae Seven months later, however, the seventh and ninth thoracic vertebrae had collapsed, although they appeared to be normal in the original radiographs Whether such changes might reflect the existence of Sudeck's atrophy is controversial (chapter III B 4, Blumensaat, Reske, and others) The role of the intervertebral disc is discussed in chapter IV E 3 and 5 Additional bibliography Bressot, O'Brien, Cimino, Cuny, Faleni, Gourdon, Helly, Masini, Masmontell, Michel with Mutel and Rousseaux, Moschetta, Oller and Bravo, Peugniez, Planitz, Proust, Rocher, Ruge, Schreiner, Solcard, and Steel

Fig 174 Photograph of a sagittal section of the spine Man, age 65 Typical changes of Kummell's disease, T 11 Only a few fragments of necrotic bone tissue of this vertebra remain The discs above and below T 11 protrude into the markedly compressed vertebra

5. Fractures of the vertebral margins and injuries of the vertebral rims

Vertebral fractures caused by forcible hyperflexion of the spine do not always have the characteristics that we have just described but may represent only a small avulsion of the vertebral margin, and this makes a rather difficult diagnostic problem since it resembles the separation of the vertebral margin caused by anterior prolapse of disc tissue (p 151, Hetzar, Salvatori, Schmidt) On this subject there appears to be considerable contradiction between anatomicoradiologic and clinicoradiologic observations (see p 153) Fractures of the vertebral margins (most common in association with other vertebral fractures) include not only fragments of the bony rim, but portions of the vertebral body (figs 175 and 176) Schmorl observed a case in which the detached vertebral margin united with the vertebral body (figs 177 and 178) Hetzar, with a vast radiographic material

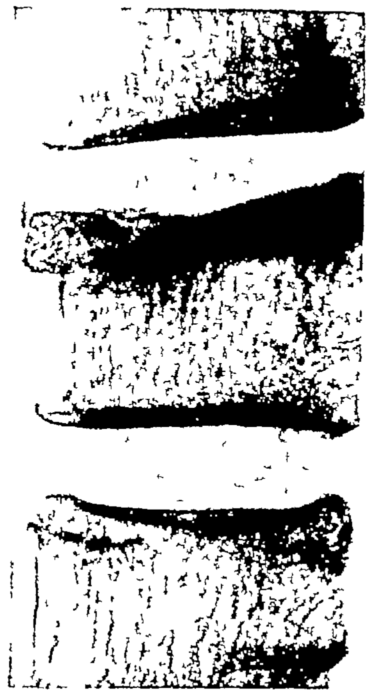


Fig 175 (left) Lateral radiograph of a sagittal section of the spine Woman, age 34 Slight compression fractures of the superior portions of T 12 and L 1 Fragmentation of the anterosuperior segment of T 12 Smooth triangular fragment detached from the anterosuperior margin of L 1

Fig 176 (right) Lateral radiograph of a sagittal section of the lumbar spine Man, age 75 Compression fracture of L 3 with anterior displacement of a large fragment detached from the anterosuperior portion of the vertebra Beginning osteophytosis on the superior margin of L 4 (see chapter V)

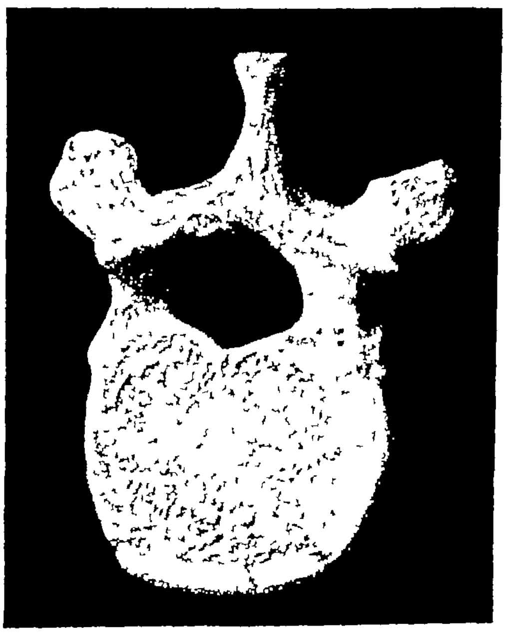


Fig 177 (left) Photograph of the superior surface of a macerated thoracic vertebra (T 11) Man, age 33 The anterior portion of the vertebral rim is detached, and is displaced slightly anteriorly (fracture of the vertebral rim)

Fig 178 (right) Lateral radiograph of a macerated specimen of the spine which contains the vertebra (T 11) shown in figure 177 (arrow) Slight wedging of T 11

at his disposal has made a schematic classification of the various forms of marginal fracture, emphasizing their radiologic features and differentiating them from the changes that follow disc prolapse (see p 151 ff)

Marginal fractures involving exclusively the superior margins are most often seen in the thoracolumbar region, since this is the area in which the shearing forces are the greatest Several adjacent vertebrae may be involved (fig 175) The small detached fragment is displaced forward and downward, and this separation provokes fissuring of the intervertebral disc (p 174) Whether the small bone fragment occasionally seen at the anteroinferior border of a cervical vertebra is a true marginal fracture, or simply a separation, is as yet unsolved (Strauss et al) Zones of bone inclusion in the anterior portion of the disc must be considered in differential diagnosis (see p 171) Although the identification of these osseous deposits is quite simple in the anatomic, the interpretation of the radiographic findings is beset with difficulties These have been discussed in an article by Rosenthal, but we do not find ourselves in complete agreement with his methods of interpretation

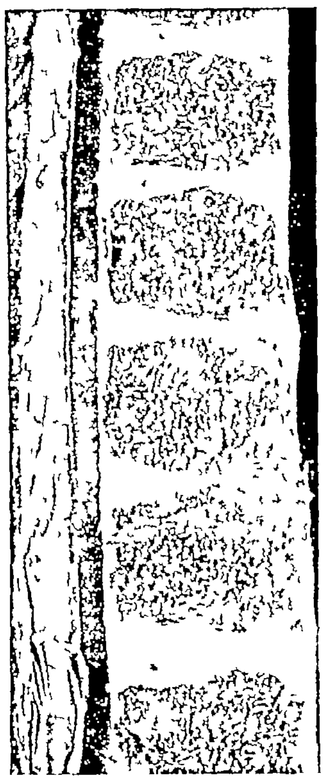


Fig 179 (left) Photograph of a sagittal section of the thoracic spine Girl, age 13 Marked narrowing (especially anteriorly) of the T 10—T 11 disc space, less marked narrowing of the T 9—T 10 space

Fig 180 (right) Radiograph of the specimen shown in figure 179 The narrowing of the T 10—T 11 disc space permits anterior contact of the margins of T 10 and T 11 Irregularity of the vertebral rims of these segments Similar, but less marked changes at the T 9—T 10 level Changes probably represent trauma

In adolescents, whose bony rims are not yet firmly united with the vertebral bodies, hyperflexion may result in the crushing of the bony rims (figs 174—183) Healing results in narrowing of the intervertebral space, either in its entirety or in its anterior portion, and examination of such a disc will reveal fissuring and evidence of crushing The anterior portion of the bony rim is fragmented, usually both of the adjacent rims are involved with calcification of the anterior segment of the disc occurring as part of the healing process (fig 183) Only a few such cases, mainly in the middle and lower thoracic spine, have been observed and study of a larger material is badly needed Hauberg has described cases with similar radiographic findings, but considers them as representing juvenile kyphosis (see p 198)

6. Separation of the cartilaginous plates

Separation of the cartilaginous plates is a very rare traumatic lesion of the spine It was first described by Luschka, and Schmorl's collection contains a few adolescent spines which exhibit this type of injury following severe trauma Since the separation occurs in the area of cartilage proliferation, it resembles the epiphyseal separations seen in other parts of the skeleton (Ruge) The trauma may produce tearing of the ligaments, fractures and dislocations of the articular processes with resulting lateral dislocation of a segment of the spine The possibility of this lesion in the adolescent arises from the relationship of the disc and the vertebral cartilaginous plate These are firmly united by strong fibers of the annulus which penetrate the cartilaginous plate and the bony rim (see p 8) The attachment of the cartilaginous plate to the disc is much more firm than its attachment to the vertebral body (Schmorl) In adolescents, the bony rim is separated from the

vertebral body by a thin layer of cartilage representing the extension of the cartilaginous plate (fig 13), and consequently, strong shearing forces, *e g*, hyperextension and rotation of the spine, occurring in adolescents may produce separation of the cartilaginous plate Fusion of the bony rim and the vertebral body in the adult prevents this separation from occurring

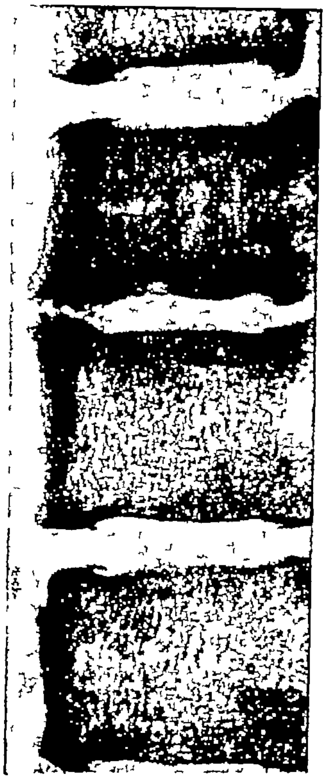


Fig 181 (left) Photograph of a sagittal section of the thoracic spine Woman, age 22 Crushing of the anterior portions of the T 9—T 10 disc with involvement of the adjacent vertebral rims

Fig 182 (center) Radiograph of the specimen shown in figure 181 The marked irregularity of the involved vertebral rims is easily seen

Fig 183 (right) Lateral radiograph of a sagittal section of the thoracic spine Woman, age 24 Damage (probably trauma) to the discs T 8—T 9 and T 10—T 11 Anterior ossification of the T 8—T 9 discs Thinning and beginning ossification of the T 10—T 11 disc

All of the cases of cartilaginous plate separation which Schmorl examined were fatal cases and since his studies included only fresh injuries he was unable to predict the course of possible healing There are no published observations which would help us to decide whether subsequent growth of the vertebral body is disturbed

H. Injuries of the vertebral appendages

1. Fractures of the vertebral arches and of the articular processes

In general, the radiologic diagnosis of a traumatic lesion of the vertebral body presents no great difficulty when we are confronted with vertebral collapse, wedging, etc, but this is not true when the trauma is to the arch The superimposition of the images of numerous bony structures (the articular process, the ribs in the thoracic area, etc) tends to obscure the fracture line or displacement of fragments When there are degenerative changes present, the complication is even greater Planigraphy is of material assistance when such lesions are suspected

Fracture of the vertebral arch is a frequent complication of fracture of the vertebral body (Hellner and others), and Böhler believes that all compression fractures are accompanied by tearing of the

ligaments and vertebral arch fractures For this reason he insists that reduction should be un taken in all cases of vertebral fractures in an attempt to restore the normal anatomic relation (cf p 86)

Isolated fracture of the vertebral arch can result only from direct trauma, sometimes associ with dislocation Numerous writers have described fractures of the arch (Hellner, Gold, R M Lange, v Oettingen, Oehlecker, Reisner and others), and have discussed in detail the difficu encountered in the radiologic diagnosis of accompanying cord injuries by fragmentation and placement Horizontal fractures of the arches are very rare (Marx) Schmieden's statistical stu show that 43 per cent of vertebral arch fractures are fatal and that only 20 per cent exhibit hea Excess callus formation is common, leading to ankylosis of the involved segment Fracture of posterior arch of the atlas (C 1) is very rare (Morisi and Belle)

Fracture of the interarticular portion of the vertebral arch, resulting in traumatic spond listhesis (figs 67 and 68), has been frequently described It seems to occur most often in the where a developmental defect in the isthmus occurs (Abraham, Böhler and Heuritsch, Reis see chapter VIII A)

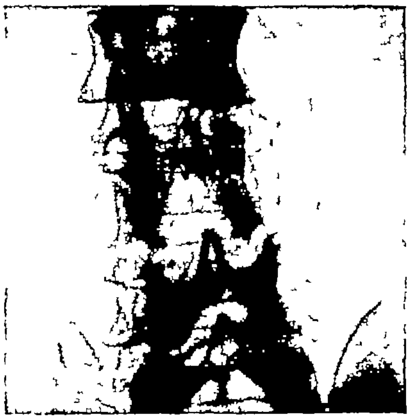
Isolated fractures of the articular processes are generally considered to be rare (Erben, G Jaki, Ludloff, Ruge, Simonsen and others), but they occur rather frequently in association vertebral body fractures and with injuries of the vertebral arches Planigraphy is of great assist in the recognition of these fractures (Sicard and Gerard) One must be careful not to confuse t with developmental nonfusion of the apophyses of the articular processes (chapter II B 8)

2. Fractures of the spinous processes

There is a steady increase in the volume of literature reporting these fractures, which occur ei as avulsion fractures (Boss, Hancken, Sandahl, Neugebauer), or as the result of direct trau (Barte, Gold, Magnus, Ruge) Long-known among cricket players (Henschen), they have b observed in recent years in persons returning to heavy manual labor (*e g* , digging) after a pe of inactivity (Canigiani, Magnus, Metge, etc) Since digging seems to be a rather constant etiol factor, the lesion has been described as "shovel worker's fractures" and many consider it to b type of "fatigue fracture" (Gerstel, Rostock) The medicolegal aspects of this injury had v discussion in the literature (Kaspar, Koeppchen and Bauer) Fractures resulting from the of the trapezius, the rhomboid and the serratus superior posterior muscles usually occur in cervicothoracic area of the spine This type of fracture is very rare in the lumbar region (Göt Schütz, Küttner) As a rule, only one process is fractured and multiple fractures are very r (Henschen, Wagner, Wolf) (figs 184 and 185) Muscular action produces downward displacem of the detached process (Reisner, Schütz) The anteroposterior radiograph shows a typical linear zone of increased density representing the fracture (fig 184) Oblique projections may be useful (Sitt) Bibliography Altschul, Bofinger, Boriani, Debusch, Dessaint, Gerber, Grashey, Güntz, Hoffmann, Jaki, Koeppchen, Koeppchen and Bauer, Ludwig, Matthes, Reischauer, Rohde, Schmieden, Schmitt and Wisser, Sommer, Stamm, Veit, Volkmann, Wachs, Zollinger

Figs 184 and 185 Lateral and anteroposterior radiographs of the cervicothoracic spine of a young man Fractures of the spinous processes of C 6, C 7, T 1 and T 2 In the anteroposterior projection the fractures are seen as doubled contours Typical displacement of the fragments is seen in the lateral projection

W Müller has described fractures of the spinous processes in zones of osseous rearrangement (umbau-zones) and Wachs calls them "spontaneous fractures" Wachs has reported spontaneous fractures of the spinous processes, while Schmitt and Wisser regard fractures of the tips of the spinous processes as evidence of aseptic necrosis of the apophyses Maxen regards these fractures as related to prolapse of a cervical disc In fractures of the vertebrae with lateral displacement of the fragments (see p 92) a simultaneous horizontal fracture of the spinous process may be observed (Böhler, Wachs)



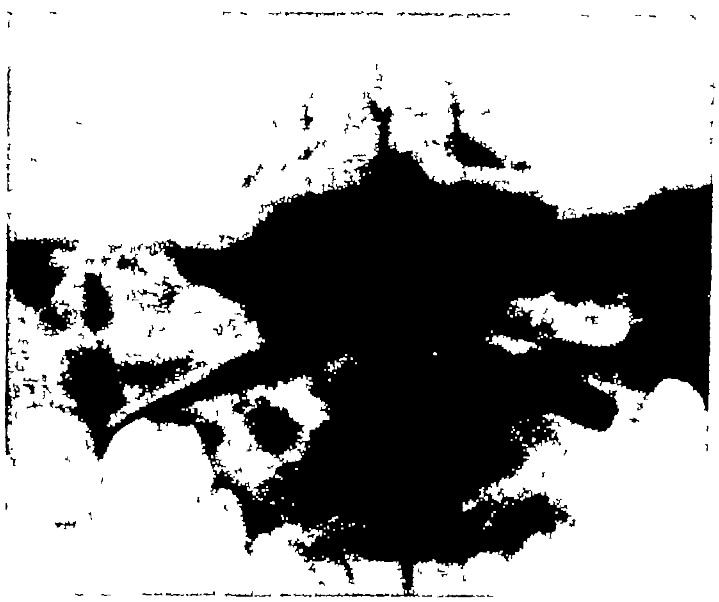


Fig 186 (left) Radiograph of the lumbar spine of a man of middle age Old fractures of the left transverse processes

Fig 187 (right) Anteroposterior radiograph of the upper cervical spine (through the open mouth) Boy, age 14 Faulty alignment of C 1—C 2, corrected by manipulation

3. Fractures of the transverse processes

These fractures are most often seen in the lumbar area and are of considerable importance because of the ease with which they may be confused with "lumbar ribs" (see p 50) and with other developmental variations (Brink, Darbois and Salol, Ernst and Römmelt, v Hayek et al) Radiographically, they may be mistaken for renal calculi (Mériel and Baillat) or for calcified nodes, and they are described rather frequently in the literature As to the mechanism of their production, there is general agreement that they are indirect fractures resulting from muscular contraction (Boidi-Trotti, Boss, Caputo, Fränkel, Jaki, Levy, Magnus, Pecirka, Schiessl et al), although some believe that they may result from direct trauma (Barta, Chevrier and Elbim, Chavannaz, Ernst and Römmelt, Lange, Niedlich, Ott, Quaintance, Winterstein and others) They may occur as isolated fractures but, according to Quaintance, 27 per cent of them are associated with vertebral, pelvic or rib fractures The fracture line is usually parallel to the sagittal plane and the detached fragment may be of variable size The case reported by Gortan with both processes of L 1 fractured in the horizontal plane is unique In order of their frequency, the processes involved are those of L 1, L 3, L 2, L 4 and L 5 (Magnus), and one or several processes may be fractured either unilaterally or bilaterally (Corret, Forton, Fumagalli, Magnus, Ott, Tosche, Wagner) Occasionally, but not frequently, the transverse processes of cervical or thoracic vertebrae may be fractured (Levy) The muscular pull usually results in downward displacement of the detached fragment (fig 186) sometimes to such a degree that no bony union occurs (Quaintance and others) During healing, excess callus formation may invade the surrounding muscles (Molineus) Bibliography Cataliotti, Chierici, Dupont, Gross, Hennes and Wolf, Herdi, Johow, Kivilaakso, Latten, Ludwig, Masini, Montant, Otto Schulze Gocht, Zuckermann.

4. Dislocations of the small vertebral joints

All vertebral dislocations are accompanied by dislocations of the small joints (see p 93 and chapter I B) and, ordinarily, with involvement of the intervertebral disc The mobility of the

"motor segment" is, to a great degree, dependent on the small joints and the disc In all dislocations, the ligamentum flavum (bridging the small joints) is injured (chapter I D, III M) It is difficult to estimate the frequency with which transient dislocation of the small joints occurs in vertebral trauma It is common in the upper cervical spine (p 93) since the vertebrae form true articulations (p 23) in contrast to the firm union formed by the annulus fibrosus in the lower spinal areas An anatomic variant in the interrelationship of the uppermost cervical segments (fig 187), although frequently described as subluxation, is, in fact, a fixed misalignment (Zukschwerdt) Its relationship to cephalgia following head injuries and its correction by manipulation has excited a considerable degree of interest tempered with skepticism (Gutmann, Säker, Sollmann, etc , see also chapters I H, III G 1, IV B 4, VIII) Additional bibliography Biedermann, Decker and coll , Derbolowsky, Dreyer, Gelehrter, Matzdorf, Mau, Werne

I. Infections

1. Tuberculosis

For over one hundred years it has been known that a vertebra may be the site of an infectious process as may any other skeletal structure In 1824 Wenzel described an anatomic section which demonstrated tuberculosis involving several vertebrae and in the past half-century other infectious processes have been recognized Quincke, who was the first to study the problem, introduced the term, "infectious spondylitis " The most common vertebral infection is tuberculosis (Pott's disease) and vertebral tuberculosis is the commonest form of skeletal tuberculosis The most frequently involved region is the thoracolumbar spine, with the lower lumbar area, the sacrum and coccyx, and the cervical spine affected much less often The disease may appear at any age, although it occurs in the first decade of life in 50 per cent of all cases, and in only 25 per cent does it appear after the age of 20

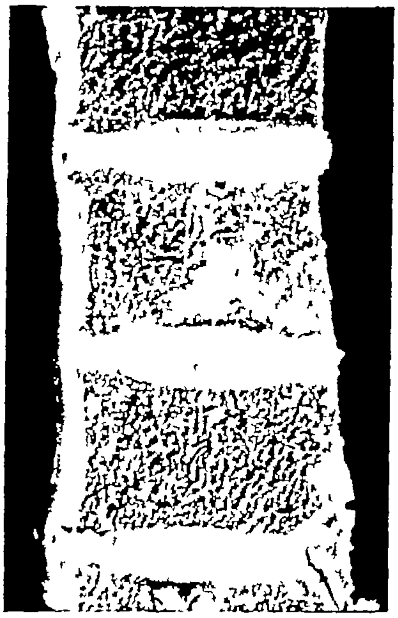
The great clinical importance of Pott's disease has stimulated much investigation, and numerous studies of vertebral tuberculosis have been published, richly documented with anatomic and radiologic observations We shall, therefore, concern ourselves here with only a few special characteristics, which will apply equally to various other types of infectious spondylitis We will discuss involvement of the intervertebral disc in chapter IV F, and for detailed description of the clinical and radiographic findings the reader is referred to the works of Brocher, Freund, Gold, Janas, Konschegg, Kremer and Wiese, Kofmann, Lange, Maluche, Sgalitzer, Strukow and others

Vertebral tuberculosis commonly begins in the anterior vertebral wall, external to or in the vicinity of the cartilaginous plate (fig 188) Although the small necrotic foci are easily recognized in an anatomic specimen, they are difficult to identify in the radiograph Chasin and others have shown that foci of less than 1 5 cm in diameter are not demonstrable in a conventional radiograph, but may be recognized by body-section radiography It is not until a lapse of time of from three and one-half to five months after the beginning of the infectious process that the first trabecular destruction may be identified in a radiograph Planigraphic sections may permit earlier recognition (Keller) There are, however, other radiographic findings which may permit a diagnosis of infectious spondylitis to be made These are narrowing of the intervertebral space and the appearance of a fusiform paravertebral shadow The narrowing of the disc space may represent either bacillary destruction of disc tissue (cf chapter IV F 2) or prolapse of the disc into the necrotic vertebral body (see p 138) The paravertebral shadow is produced by extension of tuberculous granulation tissue and the formation of purulent material between the vertebral wall and the longitudinal ligament The resulting abscess is, commonly, fusiform in shape It may be a so-called "wandering abscess," *i e* , the abscess formation occurs at some distance from its point of origin

When the diagnosis is difficult, aspiration may be the deciding factor (Craig, Frankel, Valls with Ottolenghi and Schajowicz), and at the same time antituberculous drugs may be administered (Drexler and Stracker)

The abscess of tuberculous spondylitis very rarely extends posteriorly to involve the peridural space Commonly, it extends anteriorly and laterally along the anterior and lateral surfaces of the vertebrae and follows well-defined pathways These features are discussed in detail by Baccaglini, Haberler and Risak, Konschegg, Königswieser, Rummelhardt and others

The process may also extend itself by osteoperiosteal infiltration, passing along the anterior longitudinal ligament to involve and to destroy distant intervertebral discs (Guiliani and Volkert, Jentschura, Malluche, Scherb, Schultes and others) This mechanism is common to all of the forms of infectious spondylitis (fig 341)



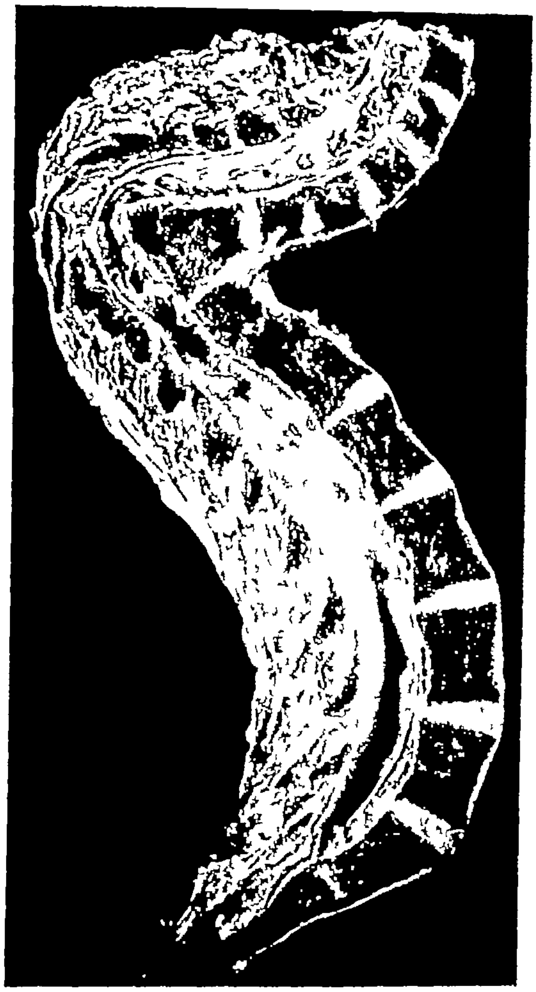


Fig 188 (left) Photograph of a sagittal section of the thoracic spine Elderly man Early stage of Pott's disease involving T 4 Triangular area of necrosis No disc involvement

Fig 189 Photograph of a sagittal section of the spine Old healed tuberculosis with gibbus deformity Marked elongation of the lumbar vertebrae at the crest of the curvature

Involvement of several vertebrae is common and, according to Gold and Rummelhardt, occurs in 50 per cent of all cases When adjacent vertebrae are affected, the disease has extended from one to the other by disc involvement Hanson believes that the simultaneous infection of two contiguous vertebrae is explained by the presence of a single artery forming their blood supply, but this hypothesis is still to be confirmed histologically Involvement of more than two contiguous vertebrae (figs 189 and 190) appears to be rare, occurring in only 0 5 per cent of all cases Involvement of several separated vertebrae is indicated, in the clinical literature, to occur in from 1 to 4 per cent of cases (fig 191, Berger, Rianapoli, Paltrinieri), but anatomic studies have shown that this figure is much too conservative since many small foci are not to be detected radiographically

Tuberculosis of the vertebral arches is very rare (Huriez and Lambert, Kremer and Wiese), and Novak found such involvement in only 8 of 2,202 cases of vertebral tuberculosis

The sequelae of tuberculous spondylitis merit our special attention The clinical and radiographic findings are very complex and differential diagnosis presents difficulties for both the clinician and the radiologist which must be overcome A block vertebra, for example, may result from the spondylitis of tuberculosis or some other infectious disease, from trauma or may be of developmental

origin Pott's disease with gibbus deformity may heal, with bone regeneration and the re-establishment of a regular osseous trabecular pattern (fig 189) It is not unusual to observe such a gibbus with 6 to 8 vertebrae fused into a solid block, with no vestige of a disc space remaining, and with

Fig 190 (left) Lateral radiograph of a sagittal section of the spine Woman, age 44 Advanced tuberculosis with gibbus deformity and with destruction of numerous vertebrae Areas of calcification Elongation of several lumbar vertebrae

Fig 191 (right) Photograph of a sagittal section of the spine Woman, age 64 Tuberculous foci in T 5, T 6, T 10, T 11 L 2 and L 3 with involvement of their discs

the trabeculation adapted to the new stress condition In the early stage of healing, the disease focus is surrounded by sclerotic bone, giving rise to an "ivory vertebra" (see p 86), but as healing progresses a normal trabecular pattern appears

Examining a thoracic spine with Pott's disease which has healed with ankylosis and kyphosis, one is struck by the considerable increase in the height of the vertebral bodies of the lordotic lumbar spine (figs 189 and 190), sometimes amounting to an increase of one-third in vertical diameter These "tall vertebrae" can develop only when the disease occurred during the growth period, *i e*, before the disappearance of the growth zones This phenomenon was first described by Ménard

These changes, however, are not limited to tuberculous spondylitis but may occur in any of the kyphoses or kyphoscolioses which involve the spine before the end of the growth period Heuer's speculations on the pathogenesis of scoliosis were based on the observation of these phenomena

The stages of healing of tuberculous spondylitis and their clinical and radiographic aspects have been described by numerous writers Finck, Finder, Lindemann Perotti, Ratti, Schiller and Altschul et al Groos has reported a case of healing with complete restitution of the normal anatomic features of the vertebra

Therapeutic success depends on an early diagnosis, the degree of involvement and the type of treatment instituted The most rapid and the most permanent good results follow surgical elimination of the disease focus and the use of antituberculous drugs (Kastert, de Sèze and Debeyre, Wilkinson et al)

Spinal fusion frequently employed in the past, has lost its pre-eminence Moser suggests the resection of an entire vertebra Bibliography Albee, Anbaniac, Bérand-Picard, Bauer and Jenner, Berg, Birgard, Blumensaat, Bosworth and Levine, Bujorica, Castiglione, Coquelet, Drexler and Stracker, Ducrey, Eichenholtz and Mayer, v Finck, Graziansky, Hanson Herlyn and Kochs, Kofman Nitsche, Orell, Perusi, Soldi, Weisman and Tulcinski

Boerema's statistical studies demonstrate that 53 per cent of patients with tuberculous spondylitis die within 10 years after the onset of the disease, nearly always from pulmonary tuberculosis

The relationship of trauma to tuberculous spondylitis has been the subject of numerous publications (Derganz, Franzen, Gold, Haumann, Jaeger, Liechti, Leclercq, et al) After a discussion of differential diagnosis, Ruge states the present consensus, "When tuberculous spondylitis develops after spinal trauma, it is more probable that the trauma activated a latent tuberculosis than that a hematogenous embolism of acid-fast organisms was provoked by the trauma " The criteria essential to link trauma with the activation of latent tuberculous foci have been established by Geissendörfer

2. Osteomyelitis and infectious spondylitis

Osteomyelitis of the vertebral column occurs very infrequently as compared with other sites of involvement, and represents only 2 per cent of osteomyelitis (Hahn) It is mainly of staphylococcic origin (Armanet, Carnot, Casson, Gold, Kocher, Lenner, Lexer, Mallet-Guy, Oehlecker, Puhl, Raszeja, Semb and Sundt, and others), and only rarely is due to streptococci (Largot and Solal, Gold, Puhl et al)

There are numerous disease entities, during the course of which infectious spondylitis may occur. They include

Actinomycosis (chapter III G 5),
Appendicitis (Hellner),
Brucillosis (Bartsch, Brocher and Parhami, Franzen, Jensen, Krieger-Lassen, Palagi, Pratesi, Redell, de Rienza, Sandstrom),
Carbuncle (Canigiani),
Diphtheria (Fraenckel, Radt),
Erysipelas (Fraenckel, Radt),
Furunculosis (Genscher),
Glanders (Schmorl),
Gonorrhea (Fraenckel, Genscher, Radt),
Influenza (Coniglio, Puhl, Schmorl),
Leprosy (Beitzke),
Lues (chapter III I 3),
Malaria (Delic, Prokowsky, Puhl),
Measles (Cobb, Puhl),
Meningitis (Epstein),
Paratyphoid (Anchersen, Klose, Puhl, Waaler),
Peritonitis (Hellner),
Pneumonia (Fraenckel, Glogner, Kalina, Oehlecker, Puhl, Schaggi)
Pseudotuberculosis (specimen in the collection of Schmorl)
Salmonella (Miller),
Scarlet fever (Dengler, Winter),
Septic abortion (Genscher),
Smallpox (Puhl, Schmorl),
Tonsilitis (Berg, Hormann, Schmorl),
Typhus (Klose, Puhl),

Typhoid fever (Arendt, Baensch, Bertolini with Rocca, Bowen and McGehee, Bruder, Ebermeyer, Fraenckel, Gallus, Halpenny, Haselhorst, Janke, Kuhn, Lyon, Oehlecker, Puhl, Quincke, Radt, Rummel, Segre, Schmorl, Sinngrun, Sucher, Wang and Miltner et al)

Quite rare causes of infectious spondylitis in the newborn are infection of the umbilical cord (Carstens) and mastitis involving the mother's breast (Ruge) Involvement of the spine in cases of sporotrichosis (Beitzke, Meyer and Gall), blastomycosis (Allenbach with Zimmer-Sartori and Meyer,

Fig 192 (left) Photograph of a sagittal section of the lumbar spine Numerous foci of necrosis due to infectious spondylitis (unknown origin)

Fig 193 (center) Photograph of a sagittal section of the lumbar spine Collapse of T 10 due to spondylitis of typhoid origin Expansion of adjacent discs

Fig 194 (right) Lateral radiograph of the specimen shown in figure 193

Beitzke, Buschke and Joseph, Henle, Junghanns, Mumme) and coccidiomycosis (Ingham) ha, been reported Vertebral body infection has been observed to follow local and spinal anesthesia and following disc surgery (Erb, Heep, Schluter, Brussatis, Gieseking, see p 182) Pampus has reported a case of generalized osteomyelitis of the spine following trauma Several writers have described infectious processes in the upper cervical vertebrae following tonsillectomy and acute nasopharyngeal inflammation (Jones, Odelberg-Johnson, Oppikofer, Woltmann and Meyerding) The infection may manifest itself as a suppurative disease of the vertebrae or as acute arthritis of the small joints with abscess formation and subluxation

The reported cases indicate that, in contrast to tuberculosis, the vertebral arches and the processes are involved more commonly than are the vertebral bodies (Chinglia, Jorns, Oehlecker) Selvaggi thinks that they are affected in 50 per cent of all cases Kulowski, however, found involvement of the vertebral bodies more often than of the arches and processes Isolated disease in the processes may be observed (Largot and Solal, Lenner, Loben, Shehadi) Infectious processes involving the arches are usually less fulminating than those seen in the vertebral bodies, but because of the intimate relationship of the arches to the cord, neurologic disturbances are more common Chronic osteomyelitis of the vertebral arches has been observed by Hohmann and Guntz, and in one of their cases marked thickening of an articular process led to impaired mobility

Hematogenous spondylitis is a grave disease with a very poor prognosis, with death occurring in 50 per cent of cases The clinical findings of severe infection precede the radiographic recognition

of a focus of infection in a vertebra A considerable number of fresh vertebral lesions, discovered by Schmorl in his systematic examination of the spine at autopsy, were quite unexpected since the subject had had no recognizable spinal disease They appeared, largely, as *vertebral infarcts* associated with a dark red hyperemic marrow and congestion, and thickening of the anterior longitudinal ligament (fig 192) As in tuberculous spondylitis, the initial focus is close to the surface, near the intervertebral disc Radiographically, the entire spine sometimes presents a mottled appearance We are unable to give a prognosis in this widely disseminated disease As the disease progresses, slowly or rapidly, the findings of osseous destruction appear rarefying osteitis, vertebral necrosis (Radt) and a paravertebral abscess According to Oehlecker, such an

Fig 195 (left) Lateral radiograph of a sagittal section of the thoracic spine Aged man Slight sclerosis of one vertebra (end-result of infectious spondylitis) A small abscess, not demonstrable in the radiograph was discovered in the specimen Thickening of the anterior longitudinal ligament.

Fig 196 (right) Photograph Anterior surface of a macerated lumbosacral spine Bony proliferations on the lower lumbar vertebrae and the sacrum Ossification of a "wandering abscess."

abscess tends more to open into a hollow viscus (a loop of intestine, the urinary bladder) than does the abscess of Pott's disease The infection may be limited to a single vertebra with collapse of the body following the extensive bone destruction (figs 193 and 194) and may produce findings resembling those of Kümmell's disease (fig 174) Extension to an adjacent vertebra by involvement of the disc is common, as it is in tuberculosis The less fulminating infections may result in an osteosclerotic process involving part or all of the vertebral body, and producing an "*ivory vertebra*" (see p 86; fig 195) Radt describes a third form of the disease in which, for many years, there may be small *bone cavities* enclosing viable microorganisms, as are seen in the long bones Chronic sclerosis of the spinal ligaments may occur also

We wish to direct attention to a possible error in microscopy which has been pointed out by Schultz. Published articles have referred, occasionally, to small areas of vertebral necrosis These areas, studied carefully, are seen to represent minute bone fragments displaced into the marrow by the saw used in sectioning the spine

After the infectious process has subsided, healing may occur as it does, sometimes, in Pott's disease with regeneration and with restoration of normal contour and a normal trabecular pattern (Selig and Eliasoph) This, however, is of rather rare occurrence and, usually, some residual osteosclerosis persists A usual sequel of extensive destruction is a gibbus deformity involving several vertebrae

Another sequel of infectious spondylitis (and differing from the sequelae of Pott's disease) is the production of numerous osteophytes bridging the space between the affected vertebrae (Oehlecker) They must not be confused with the osteophytes of spondylosis deformans, and their development is easily followed in serial radiographs (Arendt, Fischer and Fenster, Freud, Haselhorst, Hoffmann, Oehlecker, Puhl, Roger et al) Following infectious spondylitis, especially with abscess formation, there may be extensive irregular ossification of the anterior longitudinal ligament The location and the extreme irregularity of these bone formations makes confusion with the osteophyte formation of spondylosis deformans nearly impossible (fig 196) According to Schmorl, osteophyte formation does not always accompany healing

The formation of block vertebrae after disc destruction may give rise to considerable difficulty in differential diagnosis and, the more varied the sequelae, the more complex becomes the evaluation of the etiologic factors from the standpoint of anatomic features and radiographic findings This is particularly true today, when early diagnosis and the prompt institution of appropriate therapy is the rule According to Block the mortality of vertebral osteomyelitis, which was formerly between 50 per cent and 70 per cent, has decreased to 34 per cent The past history is usually the deciding factor in differential diagnosis

The question of the role of trauma in the production of infectious spondylitis is as debatable as in Pott's disease (see p 106) Cases in which trauma may be considered as a possible etiologic factor are discussed in some detail by A W Fischer It seems certain that, in the past, the role of trauma has been overestimated (Balthasar, Kocher, Madelung, Rosenberg)

Bibliography Borchers, Celdarius, Cesarini, Chinaglia, Detzel and Hammel, Doron, Esau, Harbin and Epton, Hellner, Herlyn, Jennings, Kocht, Klein, W Lang, Lazarus, Mognot and Baumann, Rotenberg, Schmitt, Schönburg, Sternberg, Sussmann, Uhlenbruch, Whitman and Lewis

3. Luetic spondylitis

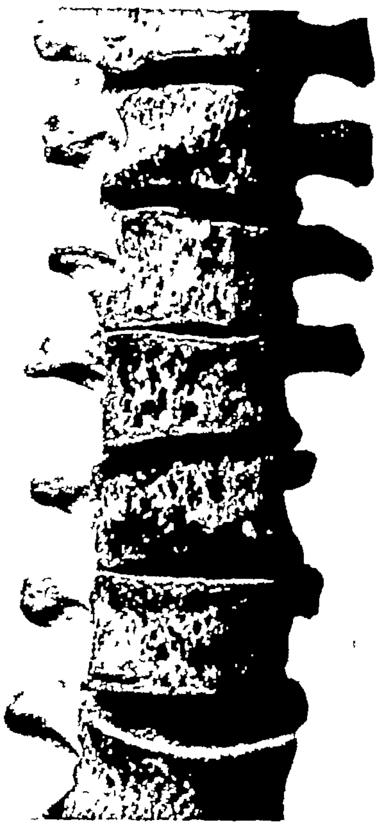
Statistics indicate that vertebral lues is a rare disease (Beitzke, Gold), and of 120 cases of bone syphilis examined by Prichotko and Moskvin only 8 had any vertebral involvement The anatomic and histologic features of this lesion have been described in detail by Beitzke The cervical spine is the usual site of the disease (Frangenheim, Gold, Grilli, Holzmann, Ingman, Schiele et al) and the thoracic and lumbar regions are much less frequently involved (Horn, Kimmerle, Ott, Tichenov, Schmorl, Sinakevic et al) The usual lesion is a gumma (Gold) with resulting collapse of the vertebral body and with dislocation (Abernathy, Breitsohl), and sometimes with the production of sequestra (Schmieden) The fact that an osteosclerotic reaction is always present is of considerable diagnostic importance (Beitzke, Horn, Prichotko and Moskvin et al) Fibrosclerotic changes in the periosteum (luetic osteoperiostitis) are found at autopsy, and these changes may produce cord injuries Differentiation between a luetic lesion and a vertebral hemangioma may be very difficult from a radiologic standpoint (May and Decourt, Willm) Various forms of vertebral lues have been described by Sprung

Healing of vertebral lues is accompanied by a very marked sclerosis, "ivory vertebra," which disappears eventually with gradual restoration of a normal trabecular pattern Charcot's spine in tabes dorsalis is discussed in connection with degenerative disc changes on page 165)

4. Hydatid cysts

Echinococcus disease of the spine was formerly believed to result from the invasion of the vertebrae by extension of disease in the adjacent structures (van Woerden), but recent studies have shown that primary infestation is not rare In the literature, reports of 406 cases showed primary spine

involvement in 41 per cent (Pozzan) Grisel and Dévé collected from the literature 190 cases with vertebral involvement The most common location is the midthoracic spine and the disease is limited to 2 or 3 contiguous vertebrae Involvement of several vertebrae, separated by normal vertebrae is rare (Rocher) In contrast to the changes in tuberculosis, the discs remain intact for a long time The vertebral body is infiltrated by cysts, varying in size from microscopic to quite large, which destroy the cancellous bone and cause fissuring (Schröder) Vertebral collapse is quite rare, but the cysts very commonly extend into the neural canal, an important diagnostic feature (Arnaud, Brütt, Cavina, Constantini and Azoulay, Denk Gulecke, Pozzan, Stoyanoff, Valls and Ottolenghi, van Woerden) Griesel and Dévé found paralysis to occur in 84 per cent of cases of hydatid cysts of the spine, as compared with only 3 9 per cent in Pott's disease[1]



5. Actinomycosis

Actinomycosis usually involves the spine by extension from a neighboring structure Its anatomicopathologic features have been described by Beitzke in a well documented study The affected spinal segment exhibits a fibrosclerotic process, with small foci of suppuration, and the vertebral bodies have a moth-eaten appearance (fig 197, Martens) Vertebral collapse occurs only with extensive destruction Although the condition is easily recognized in a fresh specimen, in a radiograph or in a macerated specimen the process may resemble tuberculosis (Suga), metastatic disease, multiple myeloma, etc Bibliography Brett, Tabb and Tucker

Fig 197 Photograph Anterior surface of a macerated thoracic spine Irregular erosion of several vertebral bodies (actinomycosis)

J. Neoplasms

1. Hemangioma

Hemangioma is the most common benign tumor of the vertebral body In the serial studies carried out at Schmorl's Institute, hemangioma was found in 10 7 per cent (*i.e*, *in 409 out of 3829* spines examined, Junghanns) Not infrequently, several hemangiomas are present in a single spine (table 6) In 409 spines exhibiting hemangiomas, there were 579 tumors of which 32 occurred in the cervical spine, 350 in the thoracic spine, 170 in the lumbar spine, and 27 in the sacrum More specifically, the distribution was T 12–47, L 4–38, L 1–37 L 2 and L 3–36, T 11, T 8, T 10, T 5, T 4, T 2

Table 6

Number of hemangiomas found in anatomic specimens of 3,829 spines

1	2	3	4	5	6	7	8	9	10
	Men			Women			Men and women		
Age	No of cases	No of Hemangiomas	%	No of cases	No of Hemangiomas	%	No of cases	No of Hemangiomas	%
0—29	235	8	3 4	195	8	4 1	430	16	3 8
30—59	732	49	6 7	533	49	9,2	1265	98	7,8
above 60	951	116	12 2	1129	179	15 9	2080	295	14 2
unknown	30	—	—	24	—	—	54	—	—
Total	1948	173	8 9	1881	236	12 5	3829	409	10 7

and T 7 were involved in order of decreasing frequency Least frequent was the involvement of the upper cervical and the lower sacral segments It is of interest that vertebral hemangioma is more common in women than in men (12 per cent in women and 8 9 per cent in men) This finding is in

Fig 198 (left) Photograph of the surface of each half of a sagittally sectioned spine Hemangioma of a vertebral body The trabeculae are decreased in number Vertical reinforcing trabeculae are seen

Fig 199 (right) Lateral radiograph of a sagittal section of the spine of a woman, age 68 Hemangioma of one vertebra including its arch Note the vertical reinforcing trabeculae (honey-comb appearance)

agreement with clinical experience, and Sandahl found that two-thirds of all clinically recognized cases occurred in women A hemangioma involving a single vertebra was observed in 66 5 per cent of spines examined, 2 to 5 vertebrae were affected in 32 8 per cent and more than 5 in 0 7 per cent All (579) hemangiomas were asymptomatic and were found only at autopsy

Vertebral hemangioma results in coarsening of the bony trabecular pattern and rarefaction, reinforced, in the case of a large tumor, with trabeculations oriented vertically as additional support within the vertebral body (figs 198—199) These vertically oriented trabeculae (discussed by Saltykow, Putschar and Makrycostas) are characteristic of hemangioma Except in this tumor, they have been observed only in a single case of Hodgkin's disease and, hence, may be considered as pathognomonic According to Schinz and Uehlinger, a coarse honeycomb arrangement of the trabeculations is an important diagnostic sign, but this does not agree with our experience

A very large hemangioma, involving the entire vertebral body, may alter the shape of the vertebra, and the lateral walls, usually concave, may become flat or even convex, the resulting "ballooning" has been described by Makrycostas and by others (Junghanns, Perman and Reisner et al)

Histologic study demonstrates the bone destruction produced by the growing tumor (Junghanns, Makrycostas, Töpfer et al), but growth is usually slow and vertebral collapse is infrequent (Holta, Junghanns, Muthmann, Sandahl) On the contrary, the reinforcement by the vertical trabeculae is frequently sufficient to maintain the involved vertebral body intact, while fracture occurs in a neighboring vertebra (Griep)

Invasion of a vertebra by hemangioma occurs not only in the central portion of the vertebral body, but occasional isolated involvement of the vertebral arch is noted and large tumors may extend from the body into the arch (fig 199) with expansion and honeycombing of the arch and

with the other features just described These features, of great importance in the radiologic diagnosis of hemangioma, and the extension of the lesion to the arches, the discs (Muthmann Trommer) and the ribs (Deetz), have been discussed by Bailey and Bucy, Gaal, Gold, Junghanns, Reisner, Schinz and Uehlinger et al

Hemangioma becomes symptomatic only when the tumor makes pressure on the nerve roots or the cord Such cases seem to have been encountered only rarely in the past, but in recent years numerous writers have reported them (Bailey and Bucy, Bell, Budinova-Smela, Clavelin and Gauthier, Deetz, Gerhard, Globus and Doshey, Gold, Guillain with Decourt and Bertrand, Jiano with Grigoresco and Vasiliu, Junghanns, Lindquist Muthmann, Permann, Putschar, Ribbert, Roith Saltykov, Scherer, Schröder, Stettbacher, Trommer, Virchow and others A preoperative

Fig 200 (left) Lateral radiograph of the sagittal section of the thoracic spine Woman, age 46 Large endosteoma of T 8 with dendritic extensions

Fig 201 (right) Lateral radiograph of a sagittal section of the spine Girl, age 19 Large osteoma of the spinous process of T 11 separating the adjacent processes and causing a slight kyphosis

diagnosis of hemangioma with vertebral arch involvement seems to have been rare, and cord tumor was more often suspected The surgeon performing a laminectomy was sometimes surprised by severe hemorrhage occurring as the tumor was unintentionally sectioned

Because of the frequency of vertebral hemangioma and the scarcity of the symptoms produced, some writers recognize two clinical forms of the lesion The first includes simple secondary vascular dilatation, while the second is a neoplasm of vascular tissue At the moment, however, we do not have sufficient data on which to base a definite opinion

Table 6 shows that, in both sexes, the frequency of occurrence of hemangioma increases with age Only from 3 to 4 per cent of hemangiomas occur in individuals less than 20 years of age, but they occur in 12 2 per cent of men and 15 9 per cent of women over 60 It would seem, then, that they develop with advancing age, and if they are congenital in origin, they remain too small to be recognized for many years after birth

Additional bibliography Alpers and Pancoast, Antoni, Barnard and Nuys, Boudreaux, Dick, Eigler, Fibiger, Fleischer, Fumarola and Enderle, Guentert, Guri, Heaney and Whitaker, Holta, Ireland, Junghagen, Lamy and Weissmann, Lievre, Litten, Livingstone, Meves, Ottonello, Parere, Pentman, Ramage and Nattas, Roederer, Sabater, Smerchinich, Stettbacher, Wagner, Wildhagen

2. Osteoma and osteochondroma

Endosteoma of a vertebral body is rare, and Schmorl found it in only 1 per cent of the spines which he examined Its histologic features, described by Makrycostas, consist of tiny foci of lamellar

Fig 202 (left) Photograph of a sagittal section of the lumbosacral spine Man, age 45 Osteochondroma, ventral surface of the promontory of the sacrum

Fig 203 (right) Radiograph of specimen shown in figure 202

osseous formation, located near the periphery or in the anterior third of the vertebra and, as may be seen radiographically, extend as radiating spicules into the cancellous structure (fig 200) We know nothing of their subsequent course, or of its relationship to "ivory vertebra" or to osteopoikilosis According to Makrycostas, such lesions may be multiple but are rarely larger than 5 mm in diameter A few larger ones were found in Schmorl's collection

In a radiograph, the vertebral endosteoma presents a typical appearance homogeneous density, oblong shape with its long axis vertical and with peripheral radiation of spicules (fig 200) Regardless of the vertebra involved, the lesion is nearly always centrally located Osteoid-osteomas have been described by Jaffé and Lichtenstein, Marzagalli, Sabanas with Bickel and Moe

Osteomas of the vertebral arch are of more frequent occurrence than vertebral endosteomas Since they are likely to give rise to clinical symptoms (while the vertebral endosteomas do not) they have been described frequently Commonly, they appear as exostoses of the vertebral processes (Agnoli) with resulting impairment of mobility, pain and even with deformity An osteoma of a spinous process, with abnormal separation of the processes, can produce narrowing of the neural canal and paralysis Figure 201 demonstrates such a case, with the condition first recognized at autopsy

Osteochondroma and chondroma are rare spinal lesions and the clinical manifestations which they provoke depend on their location. Although they may arise, occasionally, from the vertebral body (figs. 202 and 203, Necai) their common origin is the vertebral arch and the vertebral processes (Gold, Hienzsch, Ljachovitzky, Puttoni). In these locations, they may produce cord damage. Very rarely, a chondroma may occur as a nodule within the vertebral body (enchondroma lobatum, Gold).

3. Lipoma

Makrycostas was the first to describe and to study microscopically foci of fat tissue in a vertebral body, which he called lipoma. On section the lipoma is seen as a yellow mass contrasting sharply with the ruddy color of the marrow. The osseous trabeculae surrounding these foci are atrophic and rarified, and there is absence of the vertical trabeculations which are so characteristic of hemangioma. The studies which we have carried out seem to us to make it doubtful that these foci of fat are, in fact, lipomas. We found such deposits of fat in 23 out of 3829 spines studied at autopsy, or in 0.6 per cent (Junghanns). Multiple foci were found in some spines (37 foci in 23 spines) and never before the age of 50. They occurred most frequently in the lumbar and upper sacral areas, rarely in the thoracic spine and never in the cervical region. Since the fat deposits are found only in the older age groups, it may be that they represent fatty degeneration of the marrow (as occurs in the long bones) rather than actual neoplasms. We have no evidence that these "lipomas" are of any clinical significance, and they do not appear to be demonstrable radiographically.

On cross-section some of these fat foci show a very rich vascularization and, therefore, they are sometimes called "lipoangiomas." Makrycostas believes that all "lipomas" represent a healed phase of angiomas.

4. Giant cell tumor, sarcoma, chordoma, and amyloid tumor

Although giant cell tumors of the vertebrae are very rare, they have been described in the literature, from which Santos collected 23 cases. They were most commonly located in the vertebral arches and processes, but unhappily the descriptions given do not permit differentiation between benign giant cell tumors and malignant neoplasms. Some of the cases described may well have been localized fibrous dysplasia (p. 75, Farr, Gotfryd, v. Matolsoy, Milch, Partsch, Richards and Singleton, Vegh, Willard with Deforest and Nicholson).

Primary malignant tumors of the vertebrae, including Ewing's tumor, are of rare occurrence, amounting to only about 1 per cent of all primary malignancies of bone. Only isolated cases have been reported. Gorlitzer has described a richly vascularized round-cell sarcoma of the vertebra and Rohrhirsch has reported a medullary sarcoma of a vertebra which, clinically, simulated an abscess. A sarcoma in a newborn, affecting several vertebrae, was observed by Lichacev, and Bella has reported a vertebral sarcoma occurring in childhood. Gold has described an hemangioendotheliosarcoma of a lumbar vertebra. This malignant tumor usually produces sufficient bone destruction for vertebral collapse to occur, but rarely may lead to an osteosclerosis and the formation of an "ivory vertebra" (p. 86). Vertebral collapse and the invasion of the neural canal by the malignant process results in cord damage. Radiographically, one sees, quite early, a paravertebral shadow limited to the involved vertebral body and lacking the fusiform character of the abscess of Pott's disease (Bonomi, Breitländer, Kienböck, Köves, G. Lehmann, Milone, Rix and Geschickter).

Chordoma arises from the vestigial remains of the notochord and is commonly located at either extremity of the spinal column (Antoni, Boemke and Joest, Bourdeaux, Cardillo, Crowe and Muldoon, Dahlin and McCarty, Wildbolz et al.). Reviewing the literature, Coenen collected 68 cases of chordoma, of which 42 were at the base of the skull, 1 in the cervical region and 25 in the sacrococcygeal area. Mabrey collected 150 cases, of which 47 were in the spheno-occipital region, 87 in the sacrococcygeal portion of the spine and 14 were scattered throughout the spinal column. A chordoma steadily invades and destroys bone and nerve tissue with resulting neurologic symptoms and findings. Fletscher, Woltman and Adson have described 10 cases of coccygeal chordoma, a localization of some importance to the obstetrician and the gynecologist. Besides the common location at either

extremity of the spinal column, a chordoma may, in theory, occur in any spinal segment, and sporadic cases, especially in the cervical spine, have been reported (Chiari, Elsberg, Joyce et al) We must point out here that, in the literature, one finds frequently posterior prolapse of disc tissue described as "chordoma " A study of the mechanism of posterior disc prolapse will be of assistance in avoiding this error (p 141)

Amyloid tumors of the vertebrae are of extreme rarity and, at present, only one case has been reported by Mandl (Gold) The tumor had the appearance of metastatic carcinoma which had destroyed the body and arch of T 3 and had invaded the spinal cord The nature of the tumor was recognized histologically, but in the absence of any other manifestations of amyloidosis this unique case is unexplained

5. Neoplastic metastatic disease

Although the literature sometimes appears to indicate the rarity of vertebral metastases, this does not correspond with the actual facts, and perhaps arises from the failure to systematically examine the spine at autopsy (Gonzales-Angular) Since metastatic disease of the vertebrae cannot always be recognized by radiographic examination, the radiologic study of its occurrence is not entirely valid

In the systematic examination of the spine in the Institute at Dresden, we found metastatic lesions in 4 64 per cent of all spines examined The fact that Schlesinger found only 107 cases of vertebral metastases in 3500 autopsies (0 32 per cent) must reflect failure to examine the entire

Table 7

Incidence of vertebral metastasis

1	2	3	4	5	6
Primary Carcinoma	No of cases	Metastases			
		Spine		Other bones	
		No	%	No	%
Men					
Upper respiratory tract	14	—	—	—	—
Bronchi and lungs	108	36	33 3	40	37 0
Esophagus	28	1	3 6	4	14 3
Stomach	131	11	8 4	16	12 2
Intestine	21	—	—	1	4 8
Rectum	40	5	12 5	7	17 5
Pancreas	11	1	0 9	1	0 9
Gallbladder and ducts	9	—	—	—	—
Liver	3	—	—	—	—
Kidney	2	1	50 0	2	100 0
Hypernephroma	10	2	20 0	3	30 0
Urinary bladder	12	4	33 3	5	41 7
Prostate	24	16	66 7	18	75 0
Seminal vesicles	1	—	—	—	—
Penis	1	—	—	—	—
Other carcinomas	16	4	25 0	5	31 3
Thyroid	1	—	—	—	—
Sarcomas	24	10	41 7	11	45 8
Other tumors	36	2	5 6	4	11 1
Hodgkin's d	8	5	62 5	6	75 0
Total	500	98	19 6	123	24 6

7	8	9	10	11	12
Primary Carcinoma	No of cases	Metastases			
		Spine		Other bones	
		No	%	No	%
Women					
Upper respiratory tract	5	1	20 0	1	20 0
Bronchi and lungs	13	4	30 8	5	38 5
Esophagus	11	—	—	—	—
Stomach	83	13	15 7	16	19 3
Intestine	28	—	—	1	3 6
Rectum	23	1	4 3	2	8 7
Pancreas	16	1	6 3	2	12 5
Gallbladder and ducts	47	2	4 3	4	8 5
Liver	1	—	—	—	—
Kidney	1	—	—	—	—
Hypernephroma	2	—	—	—	—
Urinary bladder	9	1	11 1	1	11 1
Breast	50	33	66 6	39	78 0
Ovary	26	—	—	1	3 8
Uterus	95	9	9 5	11	11 6
Vagina	11	—	—	—	—
Other carcinomas	25	5	20 0	5	20 0
Thyroid	6	2	33 3	3	50 0
Sarcomas	14	2	14 3	2	14 3
Other tumors	30	1	3 3	2	6 6
Hodgkin's d	4	3	75 0	3	75 0
Total	500	78	15 6	98	19 6

spine In our series of 1000 autopsies of subjects with carcinoma, 176 (17 6 per cent) had vertebral metastases, but Cerepnina and Michailow found only 5 4 per cent of metastatic involvement It is possible that this difference is accounted for by incomplete study rather than by any difference in the material studied

Vertebral metastases, in the literature, are commonly regarded as secondary to malignant disease of the breast, thyroid, prostate, and the gastrointestinal tract (Hellner, Hennes, Petourand et al), but our studies indicate that bronchogenic carcinoma and sarcomas should be regarded as common primary sources (see table 7) In males who died with carcinoma of the prostate, vertebral metastases were found in 66 7 per cent The figures representing vertebral metastases from other primary tumors are bronchogenic carcinoma, 33 3 per cent, carcinoma of the bladder, 33 per cent, sarcoma, 41 7 per cent In females the figures are carcinoma of the breast, 66 6 per cent, carcinoma of the thyroid, 33 3 per cent, and bronchogenic carcinoma, 30 8 per cent Of 500 cases of proven malignant tumors, vertebral metastases were present in 19 6 per cent in males, and 15 6 per cent in females

Fig 204 (left) Lateral radiograph of a sagittal section of the lumbar spine Man, age 62 Osteoblastic metastases The process has produced an "ivory vertebra" (lowermost vertebra)

Fig 205 (right) Lateral radiograph of a sagittal section of the lumbar spine The pin is in the L 1—L 2 disc Osteoblastic metastases (bronchogenic carcinoma)

Vertebral metastases are usually multiple and two-thirds of the cases examined had both thoracic and lumbar vertebrae involved

As in the metastatic involvement of any bone, vertebral metastases manifest themselves in two forms osteolytic and osteoblastic Both forms may be present in the same spine and even in the same vertebra, and various combinations are possible (figs 204 —215)

Osteoblastic metastases, nearly always of breast or prostate origin, may involve the entire spine (figs 204 and 205) and may produce a so-called "ivory vertebra" Differentiation from "marble bones," from the osteosclerotic changes associated with the anemias and from those of Hodgkin's disease may be very difficult and, perhaps, possible only by histologic study (p 86)

Osteolytic metastases, frequently resulting in vertebral collapse, may vary greatly in their appearance (figs 206—211) A spine with multiple osteolytic metastases may have a close resemblance to multiple myeloma, both anatomically and radiographically (figs 151—153) Isolated osteolytic metastases have been mistaken for Kümmell's disease (see p 96, Trachsler)

Fig 206 (left) Lateral radiograph of a sagittal section of part of the lumbar spine Woman, age 76 Almost complete destruction of L 4 by metastases (carcinoma of the bladder)

Fig 207 (right) Lateral radiograph of a sagittal section of the lumbar spine Man, age 60 Extensive osteolytic metastases (Bronchogenic carcinoma)

Chasin conducted a very interesting series of radiologic investigations which yielded results of great interest He removed varying amounts of spongiosa from vertebral bodies and made radiographs of these specimens There was no demonstrable change in the radiographic image of the vertebral body in an anteroposterior radiograph, even after removal of all of the spongiosa, and removal of a large cylinder of spongiosa produced no recognizable defect unless the central beam was made to pass through the vertical axis of the vertebral body These studies are of importance in the evaluation of osteolytic lesions, whether malignant or inflammatory * Chasin's findings were later confirmed by Böhmig and Prévôt Body section radiography should add much to our ability to detect the presence of osteolytic lesions (Nissl)

Since osteolytic and osteoblastic metastases may be present in the same spine (figs 208—210), differential diagnosis may be difficult The history, the clinical findings, laboratory data, and the identification of a primary tumor are of great importance in the final diagnosis One must remember, too, that a metastasis which is confined to the spongiosa cannot be recognized radiographically

* Similar studies by Maner and Snure yielded identical results (ed)

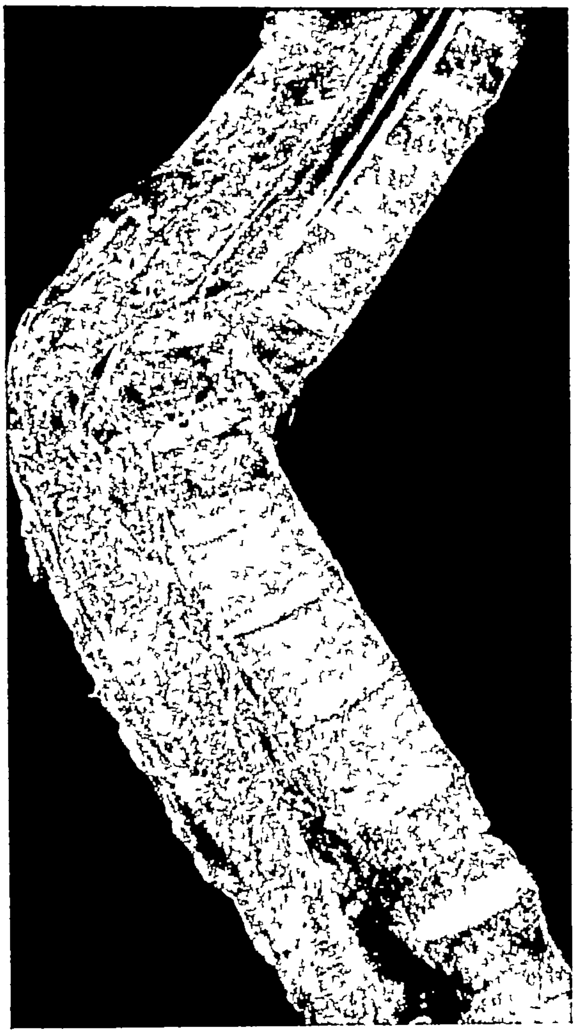


Fig 208 (upper left) Photograph Sagittal section of the thoracolumbar spine Woman, age 41 Osteolytic metastases with resulting fracture-dislocation in the thoracic spine (Primary was carcinoma of the breast)

Fig 209 (upper right) Radiograph of the specimen shown in figure 208 Both osteolytic and osteoblastic metastases involve nearly all of the vertebrae and the fracture-dislocation is readily recognized

Fig 210 (lower left) Lateral radiograph of a sagittal section of the spine Man, age 62 Osteolytic and osteoblastic metastases involve all of the vertebrae Marked destruction of one vertebra with a large surrounding tumor mass Vertebral plates still faintly seen

Fig 211

Fig 213

Fig 211 (upper left) Photograph Anterior surface of a macerated spine Woman, age 40 Multiple osteoblastic metastases L 3 and L 4 have collapsed unilaterally, but no appreciable deformity has resulted (Primary tumor, breast carcinoma)

Fig 212 (lower right) Photograph Sagittal section of several vertebrae showing metastases from prostatic carcinoma

Fig 213 (upper right) Lateral radiograph of a sagittal section of the spine Man, age 73 Extensive metastatic involvement by carcinoma of the prostate Carcinomatous osteophytes are causing narrowing of the intervertebral foramina

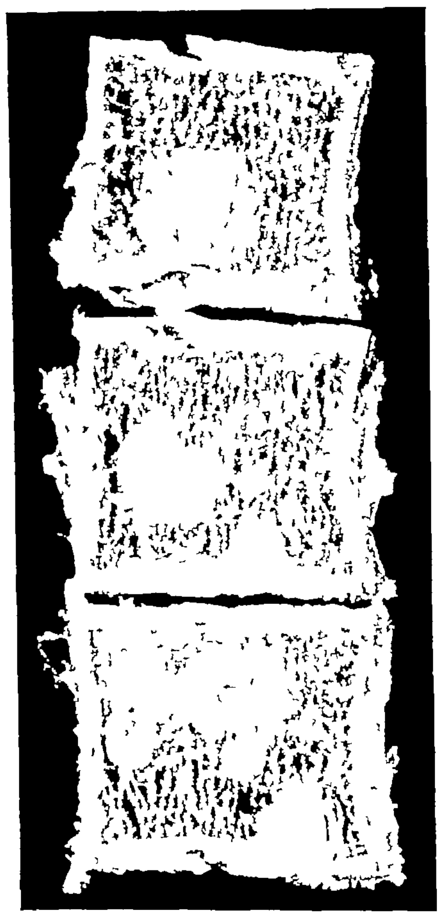


Fig 212

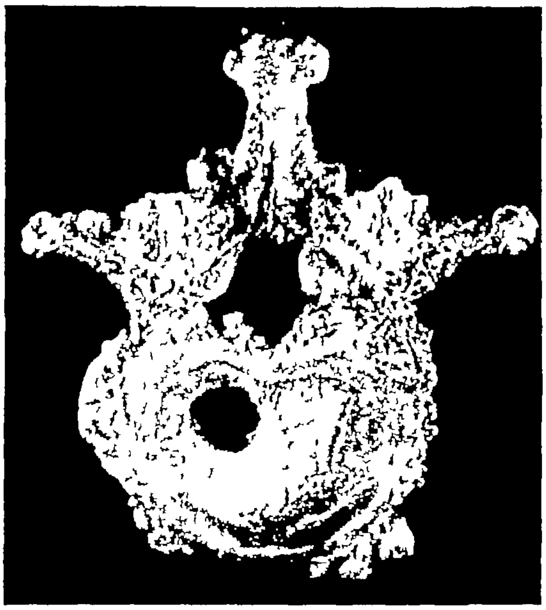


Fig 214 (left) Photograph of the superior surface of one of the vertebrae seen in figure 213 Extensive "osteophytosis carcinomatosa" of the entire vertebra Central osteolytic changes

Fig 215 (right) Radiograph of specimen seen in figure 214 Osteophytic narrowing of the vertebral canal

Fig 216 (left) Photograph of a sagittal section of the thoracic spine Man, age 56 Erosion of vertebral bodies by an aortic aneurysm Condensation of the spongiosa (specimen in the Museum of Pathology, The University of Berlin).

Fig 217 (right) Photograph of the ventral surface of a macerated spine Man, age 58 Erosion of several vertebrae by an aortic aneurysm (specimen in the Museum of Pathology, The University of Berlin)

Any part of a vertebra may be involved by metastases (the body, the arch, and the processes, fig 205), and the opinion of George and Leonard that metastases involve only the vertebral body is not supported by the evidence In fact, many vertebral metastases involve not only the vertebral body and the arch and processes, but invade the adjacent tissues and form a paravertebral mass (fig 210) With complete destruction of the vertebral body, such a paravertebral mass may simulate an abscess (fig 210, Alt, Svab et al), as may occur with primary sarcoma (p 114) Invasion of the intervertebral disc is rare, but instances of disc involvement have been reported (Schopper)

Carcinomatous osteophytosis is a rare form of metastatic involvement of the spine, usually resulting from prostatic carcinoma (Schmorl, Pürckhauer, Zemgulys) The surfaces of the vertebral bodies and the arches exhibit numerous osteophytes, the formation of which has been provoked by the metastatic process (figs 213—215) These are demonstrable radiographically This form of osteophytosis is observed only in bone invaded by carcinomatous metastases, and it seems probable that the malignant process is the stimulus needed for its production (Schmorl, Axthausen) The osteophytosis produces narrowing of the intervertebral foramina and is probably responsible for the severe pain which is a common symptom (Zemgulys) Widespread metastatic disease of the skeleton might be called "carcinomatous osteodystrophy," and such a case, associated with osteitis fibrosa cystica (Recklinghausen's disease) has been described by Hasche

Metastatic malignancy frequently produces necrosis and hemorrhage in the bone marrow which, in an anatomic specimen, closely resembles the changes of an infectious process (fig 192) These findings are, as a rule, present in numerous vertebrae and, on cross-section, they are seen as irregular yellow-brown foci surrounded by a ruddy halo Whether these findings represent superimposed infection or vascular occlusion by tumor cells deserves additional study

K. Vertebral lesions of extrinsic origin

1. Erosion by paraspinal tumors

The bony spine is frequently eroded by extrinsic tumors, especially by tumors of the pharynx, esophagus, lung or mediastinum (Picchio) Metastatic involvement of the paravertebral lymph nodes may also involve the vertebral column The invasion is from without and the cortical structure and the spongiosa are destroyed by the process as it infiltrates the marrow Hodgkin's disease and actinomycosis invade the vertebral body in a similar fashion, and in the lumbosacral area, dermoids, teratomas and malignant pelvic tumors may erode the bony structures (Goetsch)

2. Erosion by aneurysms

Aortic aneurysm may destroy one or more vertebral bodies by continuous pressure (figs 216 —218) The opposite side of the eroded vertebra may present a convex appearance, while the

Fig 218 Lateral radiograph of a sagittal section of the thoracic spine of an aged man Erosion of several vertebrae by an aortic aneurism Condensation of the spongiosa in the region of the erosion

eroded side exhibits a few vertical reinforcing trabeculae preventing vertebral collapse . . . ysms of the intercostal arteries may destroy an adjacent vertebral body and its arch (Bibli . . . phy · Gold Hubeny and Delano, D'Istria, Michaelis)

3. Hourglass tumors

"Hourglass tumors" have been described in detail by Guleke They are so-called because of . . . shape, resembling that of the classical hourglass, and are produced by the extension of the t . . . from within the neural canal through an intervertebral foramen Such tumors are of various t . . . fibromas, fibrosarcomas, ganglioneuromas, enchondromas, and, especially, neuromas Guleke . . . that fibromas and fibrosarcomas of this type arise from the posterior longitudinal ligament or . . . within the vertebral body, but Coenen held a different opinion

The passage of the tumor through the foramen widens it (Mayer) and compresses the vessel . . . nerve structures Conversely, metastatic malignancy and Hodgkin's disease may pass from . . . paravertebral area through the intervertebral foramina into the neural canal Compression of . . . roots and the cord is a regular occurrence with hourglass tumors Bibliography Antoni, Lind, . . . Stefan

4. Widening of the vertebral canal

Extramedullary and intramedullary tumors may produce increased caliber of the neural c . . . as first described by Elsberg and Dyke In an anteroposterior radiograph this is recognized b . . . increased interpediculate distance, and this is observed in about 10 per cent of intramedu . . . tumors, and in from 30 to 50 per cent of extramedullary growths Bibliography Busch and Sch . . . mann Elsberg, Kloss, Stefan

L. The spinous processes

If the lumbar spinous processes are unusually large and if the lumbar lordosis is marked, . . . processes may be in contact with one another This results in destruction of the interspinous ligam . . . and the formation of pseudoarticulations These have been called "interspinous diarthroses" (M . . . 1824), "kissing spine," "spinous osteoarthrosis" and "Baastrup's disease " Hypertrophic cha . . . develop on the contiguous surfaces, with more or less calcification of the remnants of the ligam . . . (interspinous ligaments, supraspinous ligaments and the ligamenta interarcualia) These cha . . . may produce pain Bibliography Josenhans, Reinhardt, Schumann and Trautmann, Yamada e . . .

M. The small vertebral joints

As we have pointed out elsewhere these articulations may be affected in a number of pathol . . . processes which involve the spine It is necessary, now, only to add a few general remarks in summ . . . Because of the technical difficulty of their radiographic demonstration, the small vertebral jo . . . have been neglected in the radiologic literature (Oppenheimer) Guntz has described the anato . . . features of these articulations and their radiographic appearance has been discussed by La . . . Recent studies by Emminger, Töndury et al have increased considerably our knowledge of th . . . articulations (including menisci, fat pads, mobility, etc) and interest in them has been rene . . . (see also chapter I B) Nevertheless the role of the small vertebral joints in the statics and . . . function of the spine needs additional study The discovery that pinching of a meniscus or fat . . . may produce certain forms of back pain was a distinct contribution to our knowledge and help . . . substantiate the hypothesis of Heidenhoffer, who thought that such "pinching" was respons . . . for certain forms of "lumbago " The formation of free interarticular bodies (loose bodies) has b . . . described by Mannheim and Zuckschwerdt has emphasized the possibility of "locking" by s . . . loose bodies

The small joints constitute an important component of the "motor segment" of the spine (chapter I H) and a disorder of any such segment invariably affects all of the various "motor segments" Thus, osteochondrosis of an intervertebral disc (chapter IV C 2) disturbs the mobility of the small joints resulting, eventually, in arthrosis deformans of these joints Like changes occur in tabes dorsalis (fig 300) Changes which result in the approximation of two vertebrae produce articular pain and irritation of the periosteum which, in turn, may cause spasm in the adjacent muscles (Keller)

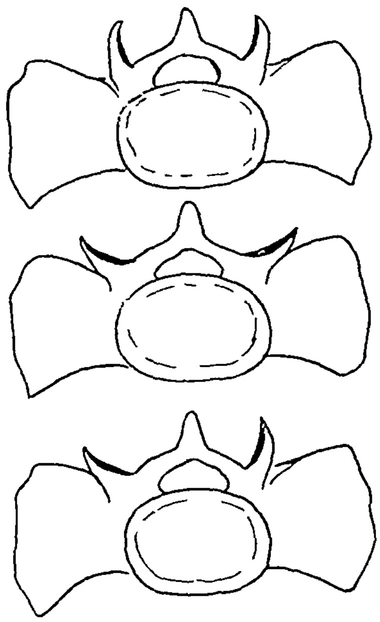


Fig 219 (left) Drawing of the base of the sacrum, seen from above Various positions of the superior articular processes Above, semilunar (12 per cent cases), center, flat (57 per cent), below semilunar and flat (31 per cent)

Fig 220 (right) Lateral radiograph of a sagittal section of the thoracic spine Man, age 76 The pin is in the T 6—T 7 disc Arthrosis deformans with osteophytes protruding into the intervertebral foramina (T 3—T 4—T 5) The uninvolved small joints are intact and the articular spaces are well-preserved

The articular processes, and the orientation of their articular surfaces, are subject to such variation that, especially in the lumbosacral area, the variation is almost the rule (p 231) These variations, the degenerative changes involving the discs, and vertebral displacement (pseudospondylolisthesis) will be discussed in another section The relationship of hypoplasia and the various other forms of dysplasia of the articular processes to spondylolysis has been described by Brocher under the title "dysplasia of the vertebral arches" (p 39)

Changes in the small vertebral joints (arthrosis deformans, *i e*, erosion of cartilage, subchondral eburnation and osteophyte formation, fig 220) are common and do not differ from those which occur in other true joints, and loose bodies may form within them (Mannheim) These changes are common after the age of 60 and are most frequently seen at the level of T 3 to T 5 and in the lower lumbar spine (M Lange) Ankylosis of the small joints may occur Surgical fusion and, in some instances, resection of the articular processes have been recommended by Foster for the relief of pain Studying radiographs after resection of the processes, Burman and Sinberg observed regeneration to occur

Complete fusion of the small joints may occur in ankylosing spondylitis (see p 220 and fig 407) In block vertebra the small joints are synarthrotic (figs 45 and 46) and this is true whether the

block vertebra is of congenital origin or is the result of a disease process We do not know whether the ankylosis results from disuse or from the pathologic process

We know but little about the acute inflammatory processes which involve the small vertebral joints (Klinge, M Lange Weil) Pharyngeal inflammatory disease has been observed as an etiologic factor in acute arthritis of the small joints in the cervical spine with a tendency to subluxation

Güntz found no significant changes in the small vertebral joints in kyphotic spines, but M Lange has seen arthrosis deformans in these joints in cases of juvenile kyphosis He thought that these changes were responsible for pain Additional study is needed to determine the extent to which the small joints participate in the ankylosing kyphoses (*e g* , senile kyphosis, etc)

Fig 221 (left) Lateral radiograph of a sagittal section of the lumbar spine of a man, age 55 Narrowing of the *intervertebral foramina by ossified ligamentum flavum bridging the small vertebral joints*

Fig 222 (right) Lateral radiograph of a sagittal section of spine of an aged man Early stage of ankylosing spondylarthritis Ossification of the longitudinal ligaments Beginning ossification of the ligamenta flava Narrowing of the intervertebral foramina Partial ossification of the ligamenta interspinalis

The changes in the small joints which occur in the various scolioses consist, essentially, of arthrosis deformans and occur on the concave aspect of the curvature (Güntz, M Lange) Since the lower lumbar area is the site of the greatest stress (M Lange), the changes are conspicuous in this region, and they are particularly marked when, in addition to scoliosis, lateral displacement of the vertebral bodies has occurred (rotational slipping, see p 230)

In spinal trauma there is frequent involvement of the small joints (Güntz, M Lange), a fact which has regularly escaped notice and has been very little studied Commonly, following vertebral fractures, degenerative changes appear in the small joints, but it is not known whether these

changes represent tearing of ligaments (as assumed by Böhler) or are due to altered stresses secondary to a gibbus deformity.

Although spondylosis deformans (see p. 195) and arthrosis deformans involve the spines of nearly all elderly people, there is no exact parallelism of the two processes (Güntz, Junghanns, M. Lange et al.). Each depends on the functional capacity of the spine, but there is a chronologic variance in their development. As M. Lange has said, "The more rapidly one of these processes occurs, and the more rapidly it spreads to involve other joints, the more slowly will appear the other process."

The ligamenta flava, lining the posterior wall of the vertebral canal, and covering the small vertebral joints, occasionally show radiologic evidence of ossification (fig. 221). Small osseous spurs arise at the points of ligament insertion and tend to bridging (fig. 221). Frequently, the interarticular spaces are bridged by the osteophyte formation and ankylosis occurs (the interarticular synostosis of Polgar). A radiograph in the lateral projection will show narrowing of the intervertebral foramina (see p. 126), but we do not know whether the ossification of the yellow ligaments is due to an acute inflammatory process or to chronic irritation. Bakke refers to it as "spondylosis ossificans ligamentosa localizata." The behavior of the ligamenta flava in such various diseases and injuries of the spine as infection, spondylosis deformans, arthrosis deformans of the small joints (see p. 195), fractures and dislocations of the vertebral bodies, and fractures of the vertebral arches, are subjects which require further investigation. The yellow ligaments are always calcified in ankylosing spondylarthritis (see p. 220 and fig. 222). The relationship of fibrous thickening or ossification of the ligamenta flava to sciatic pain is discussed in chapter IV B 2 (p. 146).

Fig. 223. Radiograph of a sagittal section of the lumbar spine. Man, age 32. Nodular calcification of the ligamentum flavum at the level of the intervertebral foramen (arrow).

N. The intervertebral foramina

Since many writers (Bechterew, Ehrlich, Grage, Oppenheim, Strümpell, Schlesinger, Zuckschwerdt) ascribe an important role in the production of radicular pain to the changes in the bony walls of the intervertebral foramina, it seems advisable to devote a brief section to these structures, the normal anatomy of which has been described in chapter I E. It frequently happens that intervertebral foramina which, in a radiograph, appear to be narrowed, are seen in the anatomic specimen to have ample room for the transit of the nerve roots and the vessels. It must be remembered, however, that the narrowing seen in the radiograph represents alterations in the bony structures occurring in various planes and that a marked narrowing may be only apparent (rather than real), especially when the axis of the x-ray beam does not coincide with the axis of the foramen.

Narrowing of the foramina demonstrable radiographically (Löw, Oppenheimer, Polgar) may be produced by ossification of the ligamenta flava (figs. 221—223) or by osteophytes arising from the posterior vertebral margins (Polgar, fig. 224). Many writers have stressed the importance in ankylosing spondylarthritis (Marie-Strümpell's disease). A lateral radiograph of a spine involved in this disease shows concentric narrowing of the foramina due to generalized ossification of the ligamentous apparatus, but the narrowing is not sufficient to make nerve root compression very likely and the foramen remains regularly oval in outline and without evidence of osteophyte formation (fig. 225). One must admit, however, that edema of connective tissue and vascular engorgement might well produce nerve root compression (Braun, Ehrlich).

Either hemangioma or Paget's disease may so thicken the vertebral arch that the intervertebral foramina are narrowed (fig 226) Marked narrowing may occur also in carcinomatous osteophytosis (fig 213) with pain resulting from nerve root compression

The intervertebral foramina may be narrowed also by soft tissue, as in "hourglass tumors" (see p 122) Lindblom has observed a case of narrowing of a foramen by prolapse of a fragment of

Fig 224 (left) Lateral radiograph of a sagittal section of the thoracic spine (macerated specimen) Woman, age 65 Numerous osteophytes on the posterior aspect of the vertebrae intruding into the intervertebral foramina (Polgar). Osteoblastic metastases (breast carcinoma) involving some of the vertebrae

Fig 225 (right) Lateral radiograph of a sagittal section of the thoracic spine Man, age 71 Advanced ankylosing spondylarthritis with complete ossification of the ligaments Some distortion but insignificant narrowing of the intervertebral foramina

disc tissue and histologic examination revealed evidence of compression of the nerve traversing this foramen He thinks that the etiology of this type of Schmorl's node is fissuring and degeneration of the annulus fibrosus, as is the case in posterior disc prolapse (see p 141) The prolapse of a Schmorl's node into an intervertebral foramen is not demonstrable radiographically Lindblom's observations point the way to a new field of anatomicoclinical research which promises to be very fruitful (chapter IV B 2)

The extent to which osteochondrosis of the intervertebral discs may narrow the foramina, especially at the two extremities of the spine, has been demonstrated by Duus, following the histologic studies of Kahlau (Duus, Kahlau and Krücke, Hadley) Narrowing of the intervertebral space results in closer approximation of the adjacent vertebral bodies with consequent narrowing of the intervertebral foramina and with symptoms which are particularly manifest during movement

These symptoms closely resemble those of posterior Schmorl's nodes (see p 141) The last presacral foramen presents features (Wepler and Kluge), which are of particular interest in lumbarization and sacralization (chapter II C 4 a)

In congenital block vertebra the fusion involves practically all of the body and arch, and leaves only a very small opening between the pedicles for the passage of the nerve roots (figs 45 and 46)

Fig 226 (left) Lateral radiograph of a sagittal section of the lumbar spine Man, age 82 Typical osteitis deformans (Paget's disease) of L 2 (including its arch) with narrowing of the intervertebral foramen There are also osteophytes present

Fig 227 (right) Lateral radiograph of a sagittal section of the lumbar spine Man, age 58 Posttraumatic block vertebra L 2—L 3 The intervertebral foramen is foreshortened The other foramina have the usual "ear-lobe" configuration

In spite of this, functional disturbances are rare, and there is almost never any evidence of root compression Vertebral synostosis following disc degeneration (trauma, Pott's disease) may occasion narrowing of the foramina by reduction of the intervertebral space (fig 227), but the reduction of the long axis of the intervertebral foramen may be accompanied by increase in the transverse diameter Diminution in the length of the intervertebral foramen is observed frequently after vertebral fracture with callus formation or with traumatic destruction of an intervertebral disc The foramen may be narrowed also by displaced bone fragments following fracture

Of much rarer occurrence is the increase in the diameter of an intervertebral foramen It is produced by osteolytic malignant metastases (figs 228 and 229), by necrosis accompanying inflammatory disease of the pedicles and by "hourglass" tumors (p 122) In these instances of apparent widening of the foramen, it does not follow that the space for transit of the nerve and vessels is actually increased On the contrary, the tumor tissue or the tissue production of an inflammatory process may reduce the space available for these structures

Spondylolisthesis and pseudospondylolisthesis also affect the shape and dimension of the intervertebral foramina With the forward displacement of the vertebral body the foramina below are elongated, while the decrease in the height of the intervertebral space reduces the vertical diameter These features are shown clearly in figures 74—79 In pseudospondylolisthesis an osteophyte

protrudes into the foramen from its posteroinferior aspect (Junghanns, Fig 411) This is seen also in arthrosis deformans of the small joints Posterior displacement of a vertebral body (retrolisthesis) also contributes to the modification of the shape of the intervertebral foramina (fig 415) Careful study of the radiograph will enable one to recognize the variations in the morphology of the intervertebral foramina, but the clinical significance of these variations can be grasped only when one considers the foramina as a whole and as a part of the 23 "motor segments," which make up the vertebral column (chapter I H) and on which the function of the spine depends

Fig 228 (left) Lateral radiograph of a sagittal section of a macerated lumbar spine Man, age 50 Metastatic involvement of the posterior portion of the vertebra with osteolytic widening of the intervertebral foramen

Fig 229 (right) Lateral radiograph of a sagittal section of the lumbar spine Osteolysis of the arch and posterior portion of the body of L 3 Destruction of the walls of the intervertebral foramina of L 2—L 3 and L 3—L 4

The peculiar anatomic features of the cervical spine play an important role in the narrowing of the intervertebral foramina, with accompanying compression of nerve roots and the vertebral artery by osteophytes arising from the margins of the joints of Luschka (p 147—156, fig 274) Hackethal believes that causalgia and Sudeck's atrophy of the extremities is caused by marked narrowing of the cervical intervertebral foramina and Sollmann proposes treatment by manipulative therapy (chapter III B 5)

Summary Narrowing of the intervertebral foramina may result from changes in their bony walls, from intrusion of soft tissues or from vertebral displacement Limited motion of a nerve root may be produced by decreased mobility of any two vertebral bodies, whether unilateral or bilateral (chapters II B C, IV B 2, IV B 4)

O. The Sacroiliac articulations and the pelvis

Because of their position at the juncture of the skeleton of the trunk and the pelvic girdle, the sacroiliac articulations are of great importance In recent years they have been the subject of extensive clinical study, but we lack systematic pathologicoanatomic investigation. It is largely radiologists who have contributed to our knowledge of these articulations and have described their normal form and their pathologic variations (Bársony, Giraudi, Happel, Horwitz and Smith, Kovacs) The radiographic depiction of the sacroiliac synchondrosis is difficult because of its oblique and sinuous form Severe fractures of the pelvis are sometimes associated with sacroiliac luxations and with

more or less marked displacement of the wings of the ilia The sacroiliac joint may be the site of the infection, especially tuberculosis, with destruction of the articular surfaces and "wandering abscess" formation Obliteration of these joints is an early finding in Marie-Strümpell's disease (p 220)

The most frequent morphologic change, frequently associated with clinical symptoms, is arthrosis deformans which manifests itself by marginal osteophyte formation (particularly in the inferior portions of the synchondroses) and by subchondral osteosclerosis These changes are responsible for a considerable degree of pain, especially with certain movements According to Duncan and Coughlan these changes, which are associated with osteitis condensans ilii (cf chapter III C 2), occur with advancing age in 90 per cent of men and 77 per cent of women Additional bibliography Bársony and Schulhof, Berent, Brackett, Bragard, Brown, Canecio, Gillespie and Lloyd-Roberts, Haggart, Haslhofer, Katz, Langenskiöld, Mitchell, Pitkin and Pheasant, Saxl, Stehr and others The healing of pelvic fractures with poor alignment of the sacroiliac articulations has a significant influence on the statics of the spine, and changes in these joints are related to back pain Changes in the spatial relations of the pelvis are of significance to the obstetrician (Kirchhoff, Martins) In the radiographic examination of the pelvis, the symphysis pubis deserves more attention Asymmetry is indicative of loosening of the pelvic ring (Kamieth and Reinhardt, cf chapter IX)

IV. Pathologic Changes of the Intervertebral Discs

The form of the spine and its functional capacity depends, to a considerable degree, on the shape and the condition of the intervertebral discs In the paragraphs which follow we hope to show clearly that changes in the discs may well produce static and functional changes in the spine which have more serious consequences than many skeletal lesions clearly demonstrable radiographically It is extremely unfortunate that these facts have not received the attention which they deserve and that Luschka' monograph, *The Amphiarthroses of the Human Body* has been forgotten This work, published in 1858, offered a comprehensive résumé of the state of knowledge then available, but it remained for the era of advanced radiographic technic to stimulate anew an interest in the multiple changes in the disc region Schmorl, in his serial examinations, was particularly interested in the pathologic changes in the disc tissues and in the interrelationships between the discs and the vertebral bodies The results of his investigations and those of his followers (Andrae, Böhmig, Güntz, Hallermann, Hammerbeck, Hildebrandt, Junghanns, Martens, Niedner, Püschel, Rathcke, Thoma et al) have offered answers to many hitherto unanswered questions, and have afforded to clinicians and to radiologists a sound foundation on which to base further diagnostic studies and investigation His work has stimulated a lively interest reflected in numerous publications in various languages (Babaintz and Perrot, Beadle, Bradford and Spurling, Franceschelli, Galland, Galleazzi, Geist, Gladyremskij, Hult, Jones, Joplin, Keyes and Compere, Macolmson, Maurice, Mooney, Podkaminski, Schajowicz, Scheuermann)

The difficulties that arise in the clinical recognition of disc lesions result from the fact that among the numerous pathologic changes which may occur, only a few can be demonstrated radiographically, *i e* , calcification and ossification In the overwhelming majority of disc changes, our conclusions must be drawn by observation of the vertical diameter of the disc space, the shape of the space and its demarcation from the vertebral body, changes in the adjacent portions of the trabecular network of the bone and disturbances in the "motor segment" which may be evaluated by "functional radiography" as described by Junghanns (pp 23, 158) As we continue our studies the relationship of the intervertebral disc to the numerous pathologic conditions of the spine will become clearer, and careful consideration of the etiology and pathology of these conditions will emphasize the very considerable importance of the disc in the physiology, the pathology and the clinical radiologic study of the spine For this reason, it seems necessary to devote more time to the discussion of disc pathology than is customary in textbooks

A. Morphologic Changes

1. Widening of the disc spaces

In the earlier discussion of the normal development of the discs and the vertebral rims, we have called attention to possible variations in the shape and the width of the intervertebral spaces and have described the numerous normal variants possible depending on the spinal segment under consideration (cf chapter I C) We have also described the congenital expansion of the nucleus pulposus and such anomalies as persistence of the notochord which may cause morphologic modifications of the disc (chapter II A 8)

Any increase in the width of the intervertebral space which is of nontraumatic origin must result from the conflict of the internal tension of the nucleus pulposus and the resistance of the contiguous vertebral bodies, and it is necessary that the hydrostatic pressure within the disc be greater than the resistance of the adjacent bone and the cartilaginous plates In the normal nuclear substance, there

is a constant hydrostatic pressure which is determined by the water content of the nucleus pulposus (p 15) This hydrostatic pressure may be increased by an increased water intake Thus far, however, we have not observed a case in which a healthy vertebral body has yielded to increased pressure in the nucleus pulposus and, in every case thus far seen, pathologic softening of the bony structures was a precedent condition Under these circumstances, the combination of body weight and the dynamic effects of the stresses of everyday life combine to effect rupture of the vertebral plates with subsequent herniation of the nucleus into the vertebral bodies As the cartilaginous plates are thinned, the disc, assuming a more or less globular shape, protrudes into the softened vertebral bodies and may, without actually rupturing the cartilaginous plates, reach the center of the vertebral body, so that the discs above and below are nearly in contact Thus, the central portion of the disc space is increased markedly in its vertical diameter and this increase may be demonstrated radiographically The expanded discs have a markedly increased water content and this may lead to cyst formation in the nucleus pulposus, also demonstrable radiographically (fig 114) Cystic space is recognizable in the radiograph as a pale area in the disc space (figs 115 and 230), and will be recognized more frequently when body-section radiography comes into more common use (Knuttson)

Fig 230 Lateral radiograph of the lumbar spine Woman, age 82 Note the widening of the disc resulting from osteoporosis (so-called "fish vertebrae") Ovoid cystic space in the region of the nucleus pulposus

Histologic sections of such discs show an increased water content of the cartilage cells, but actual proliferation of disc tissue as assumed by Brack has not been demonstrated (Schmorl) That biconcave vertebrae result from "degenerative hypertrophy" of the discs, as described by Baron and Barsony (who attribute this hypothesis to Schmorl) cannot be substantiated In the American literature, the term "ballooned disc" has been employed by Conventry with Ghormley and Kernohan

The protrusion of disc substance into the adjacent vertebral bodies occurs chiefly in osteoporosis (figs 112 – 115), in metastatic carcinoma, in multiple myeloma, and in other destructive processes which decrease the resistance of the osseous structure Among these are Paget's disease (osteitis deformans, fig 139), osteomalacia, the osteopathy of starvation (fig 128), and Recklinghausen's disease (osteitis fibrosa, fig 145) Disc expansion in vertebral body fractures will be discussed later in a separate section (p 174)

In addition to the increased width of the disc spaces, usually quite symmetric, partial or unilateral disc protrusion into the vertebral bodies may occur, a phenomenon which Smith has called "umbilication " This is the result of softening of circumscribed areas of the trabecular bony network, occurring in one of two adjacent vertebrae, as may be produced by metastatic malignancy, etc

Schmorl has always emphasized the fact that for any of these changes to occur, the disc tissue must possess its normal elasticity Discs which show evidence of dessication, of disintegration and degeneration, or even those in which fibrous tissue has embedded itself have lost their power of expansion and never, therefore, extend into the adjacent vertebral bodies Whenever widening of disc spaces, with disc protrusion into a vertebral body, is observed in the presence of chondrosis intervertebralis (yet to be described, p 158), then the widening must be ascribed to an earlier period, while the degenerative disc changes (disintegrations, lacerations, etc) have occurred later

2. Narrowing of the disc spaces

Decrease in the vertical diameter and the total volume of the disc space is an occurrence much more frequent than the changes just described In direct contrast to the widening produced by primary changes in the bone which decrease its stress tolerance, narrowing of the disc space is, without exception, the result of changes in the disc tissue, and the aging process and the stresses of everyday life play an important role in the production of narrowed spaces Infection, neoplastic disease and trauma are of secondary importance, and these facts have compelled us to deal with the various aspects of decrease in the volume and the vertical diameter of the disc space in several chapters of this book For the moment, we shall confine ourselves to a few general remarks

In the process of normal development, some disc spaces which, originally, were indistinguishable from any other spaces disappear with completion of the growth process The sacrum, for example, consisting originally of vertebral bodies of average form and with vertebral plates and bony rims, becomes a solid bone by the ossification of its intervertebral discs Rarely, the first sacral disc and remnants of the second persist into adult life In a like manner, the disc between the first and second cervical vertebrae is gradually replaced by bony tissue, so that bodies of the first cervical segment become solidly fused with the body of the second cervical vertebra Rather rarely, larger or smaller remnants of disc tissue may persist between the odontoid process which was, originally, the body of the first cervical vertebra and the epistropheus Similar conditions are present in congenital block vertebra (chapter II A 1) The remnants of the disc space are usually recognizable and one commonly notes the reduced caliber of the intervertebral foramina (fig 46) These changes produce a noticeable effect on all of the structures of the "motor segment"

Fig 231 (left) Photograph of a sagittal section of a cervical spine of an aged man Disintegration of the 4th and 5th cervical discs Sclerosis of the adjacent body surfaces Ossification of the posterior third of the disc C 3—C 4 C 1—C 2 represent a block vertebra resulting from ossification of the intervening disc

Fig 232 (center) Lateral radiograph of a section of the cervical spine Narrowing of the disc spaces with sclerosis of the adjacent vertebral plates Osteophyte formation on the vertebral bodies anteriorly and to some extent posteriorly The segments of the lower portion of the cervical column are well-preserved and the elevated bony rims are easily seen on the anterior edges of the vertebral bodies

Fig 233 (right) Lateral radiograph of a sagittal section of the lumbar spine Woman, age 83 Narrowing of the lowermost lumbar disc space accompanied by sclerosis of the adjacent vertebral body Small osteophytes project into the neural canal Pseudospondylolisthesis of L 4

If narrowing of the disc space appears, the cause must be a decrease in the volume of the disc. Such cause may be found in reduction of the water content of the discs which may occur as early as the third or fourth decade of life (Makowski, Püschel) and in the various degenerative changes related thereto These comprise changes in the nucleus pulposus, fibrillation, disintegration, etc and are included in the general changes of aging, attrition and stress They will be discussed later Inevitably, these changes result in a loss of elasticity, in decrease in the pressure within the nucleus pulposus and in narrowing of the disc space (Benecke, Böhmig) Such narrowing may occur also as a result of prolapse of disc substance into surrounding tissues, whether downward, upward, backward or forward This will be discussed in detail in chapter IV B

If the natural processes of wear and tear (discussed on p 158) assume considerable proportions, the affected motor segment may begin to manifest hypermobility and, ultimately, since the shock-

absorbing buffer has disappeared and the two adjacent vertebral body surfaces are in contact, some condensation will develop in the vertebral plates (figs 231 – 233) and the condition of "osteochondrosis intervertebralis" will appear This process, first described by Schmorl, will be discussed later in some detail (p 163)

With forward, backward, or lateral displacement of a vertebra, the intervertebral space is always narrowed (p 36, 226ff) Regarding narrowing of the intervertebral spaces in infectious diseases, see chapter IV F 2 and chapter III I 1

Lériche and Jung have described interesting observations and experiments regarding changes in the vertical diameter of the intervertebral spaces Following the injection of novocaine into the paravertebral ligaments a markedly narrowed intervertebral space resumed a normal height The nature of this phenomenon is difficult to explain because the ligaments do not possess contractile elements The injection of ligaments which were changed by scarring of inflammatory or other origin is not followed by widening of the disc space These experiments and the observations of Puky that the disc spaces which were deformed for a longer period by a spinal deformity will resume a normal shape after the correction of the deformity will have to be verified by additional observations

Narrowing may involve only a part of a space where the vertebral bodies may approach one another Such a partial narrowing involving the anterior aspect of the space (the annulus fibrosus) is particularly striking in the senile kyphosis, which follows necrosis and degenerative fissure formation within the disc (chapter VI A 3) Lindblom produced similar findings in experimental animals by subjecting the tails of rats to constant pressure Narrowing in the lateral aspect is seen in the various forms of scoliosis, but how much the narrowing reflects disc changes, and how much it reflects only bending is not known definitely (see pp 197 and 214)

B. Disc prolapse

1. Schmorl's nodes

Portions of disc tissue of variable size may prolapse and protrude in various directions Such prolapse is, as a rule, the result of the slow development of some pathologic process, but on occasion it may follow a single, sudden, abnormal stress (fig 234) Such a prolapse results in a well-defined pathologic entity which may be demonstrated by roentgen examination or by anatomic study Prolapse into an adjacent vertebra (see fig 234) is the most frequent and, in the literature, such a prolapse is commonly known as a "Schmorl's node" or "cartilage node" Originally observed by Luschka, this phenomenon has been thoroughly investigated and described by Schmorl

The possibility of disc tissue prolapsing into adjacent vertebral bodies exists only if there are present gaps in the cartilaginous plates Cartilaginous plates of normal development do not (as we have shown earlier) show any fissuring, but they do show areas of decreased resistance where, so to speak, the way has been prepared for fissure formation Such an area exists in the region of the nucleus pulposus where there is a certain degree of expansion of the disc at the site of the embryonal notochord where the cartilaginous plate is always somewhat thinner than elsewhere (p 34, fig 60) There, too, are the remains of the vascular channels and here are the small disintegration foci of irregular arrangement (Schmorl's "ossification gaps") all of which contribute to lessen the tensile strength of the cartilaginous plate (Böhmig, Putschar) Böhmig regards these foci as disturbances of growth In addition to the areas of decreased strength just described, there may exist pathologic processes which produce or, at least, favor fissure production in the cartilaginous plates These plates sometimes undergo destruction by

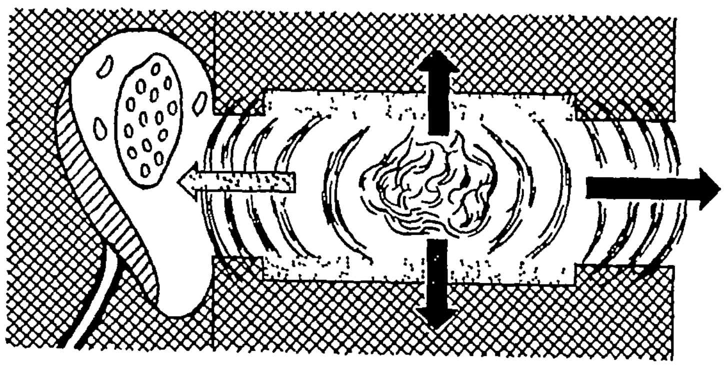


Fig 234 Schematic drawing of a sagittal section of a disc and of an intervertebral foramen, illustrating the various possibilities of prolapse of a disc Prolapse cephalad or caudad results in the formation of a Schmorl's node (figs 288—297) Prolapse anteriorly produces spondylosis deformans (chap V), while posterior prolapse produces pressure on the nerve roots and on the spinal cord itself (chap IV C 2)

Fig 235 Microphotograph of a sagittal section through the junction of the disc and the vertebral body of a young person The disc tissue has invaded the vertebral body through a rupture in the cartilaginous plate Beginning development of a Schmorl's node

Fig 236 Slightly enlarged photograph of a sagittal section of a lower thoracic disc The subject was a young man Note the rupture in the region of the nucleus pulposus with beginning production of a Schmorl's node The anterior portion of the rim of the vertebral body is on the left and bony union of the rim and the body has begun

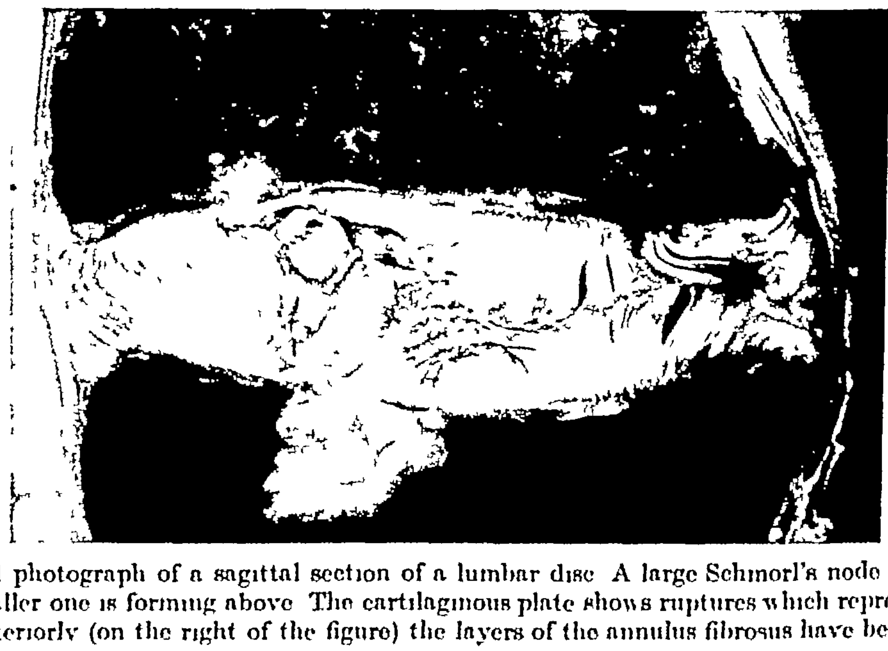


Fig 237 Enlarged photograph of a sagittal section of a lumbar disc A large Schmorl's node has formed below the disc and a smaller one is forming above The cartilaginous plate shows ruptures which represent the width of the node Anteriorly (on the right of the figure) the layers of the annulus fibrosus have been destroyed

metastatic malignancy, or by inflammatory processes originating within the vertebral body Moreover, the spongiosa may be destroyed by processes located near enough to the cartilaginous plates to destroy their support, permitting their rupture under disc pressure The degenerative changes which involve the cartilaginous plates as part of the aging process undoubtedly lower the tensile strength of the plates, and the lowered tensile strength along with the increased tension of the nucleus pulposus, plus the stresses of daily life combine to produce ruptures in the areas of lessened resistance in the cartilaginous plates The steady continuation of such tensions serves to widen the ruptures and to increase the bulging of the cartilaginous plates, and disc tissue begins to extend through these fissures (fig 235—240) Even in the absence of any disease process, the disc tissue, once having broken through the cartilaginous plates, finds in the subchondral zone, with its cribriform structure, gaps of sufficient width to permit its entrance into the bony trabecular network (figs 241—243)

Fig 238 Photograph of a sagittal section of a lumbar disc The superior cartilaginous plate has been ruptured and disc tissue has prolapsed into the vertebral body A cartilaginous wall has almost surrounded the prolapsed tissue

This prolapse of disc tisssue, or as Geipel says, "disc herniation," is subject to constantly changing elastic tensions resulting from the internal tension of the nucleus pulposus and the functional stresses imposed on the vertebral bodies Thus by the absorption of some of the fine bony trabeculae, there is produced a small cavitation which, more and more, is filled by the prolapsed disc tissue The constant repetition of the pressure stimuli presently gives rise to reactive processes in the surrounding trabecular network and, in the vicinity of the prolapsed tissue, there is formed a barrier which, at first cartilaginous (fig 240), undergoes ossification (figs 252—255) effectively preventing the advance of the prolapse process Moreover, further advance and additional pressure stimuli are effectively checked when the nuclear substance loses its resilience whether by dehydration, by the aging process or by simple wear and tear Local arrest may occur also as a result of a decrease of the volume of disc tissue and fluid, and is a regular sequel to the formation of large Schmorl's nodes

The various stages in the development may be studied best in sections cut in the sagittal plane, and the initial stages of fissure formation are easily recognizable microscopically (fig 235) The subsequent stages, including prolapsed disc tissue, the appearance of a cartilaginous limiting barrier and its ossification can be seen without difficulty by simple visual inspection of the sections (figs 236—240) (These various stages can be shown by slowly scraping away the trabecular network of a slightly decalcified preparation) The cavitations and the bony barriers are easily seen on the vertebral plates of a macerated vertebral body The cavities may be either round or oblong and may present themselves in any portion of the vertebral plate which is not covered by the bony rim (figs 241—243), but, in general, they appear in the region of the nucleus pulposus The oblong cavitations are usually oriented in the sagittal plane, but orientation in the frontal or oblique plane is equally possible

In a child or in an adolescent, the development of a Schmorl's node with release of pressure in the nucleus pulposus sometimes provokes compensatory bone formation in the opposite vertebral plate, resulting in a bulging of the plate which is sometimes demonstrable radiographically (fig 255, Schajowicz) These bulgings are, frequently, of considerable importance in medicolegal problems and in some differential diagnostic considerations, since it is obvious that they appeared during the

Fig 239

Fig 240

Fig 240 Photograph of a sag
tion of a lumbar disc Exten
lapse of disc tissue into the
the third lumbar vertebra
zone of reactive cartilage prol
(Schmorl's node)

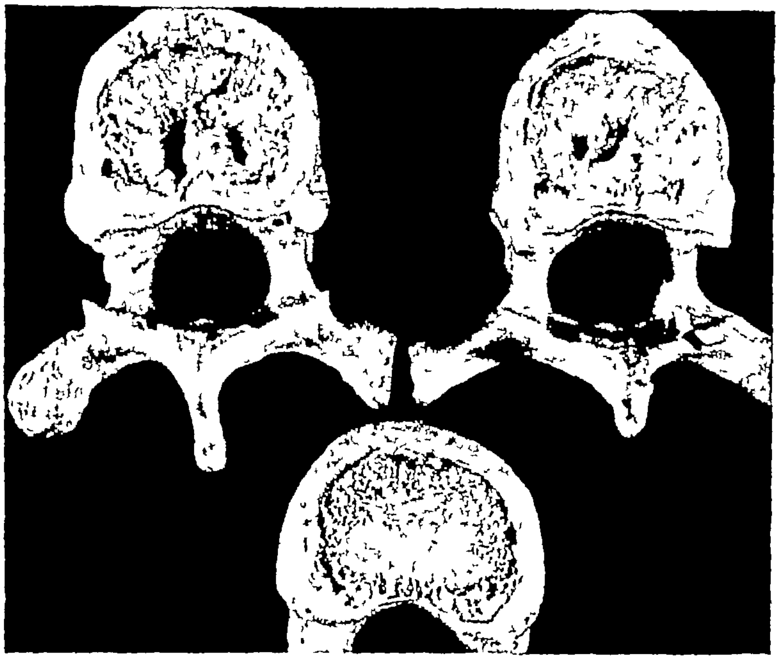


Fig 241

Fig 242

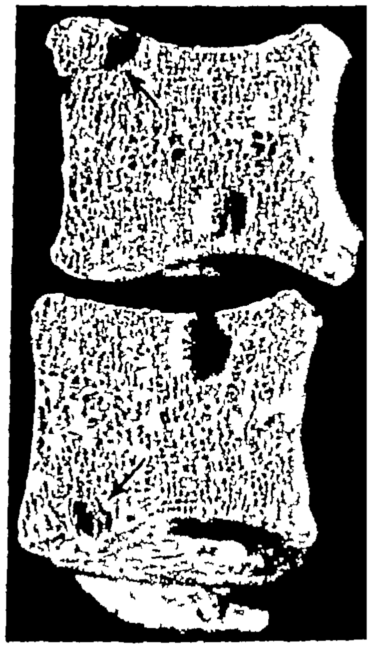


Fig 243

Fig 239 Photograph of a sagittal section of a disc and the adjacent bone Note two typical cartilaginou lying side by side (cf figs 247 and 254)

Fig 241 Photograph of the inferior surfaces of some of the cervical vertebral bodies of a man of 27 The ve plates exhibit a cribriform appearance and the bony rims have been preserved in their entirety The normal ve body seen in the lower part of the figure is for comparison

Fig 242 Photograph of the vertebral plates of two vertebral bodies after maceration These plates sho fissures produced by Schmorl's nodes and these fissures extend in longitudinal and oblique directions

Fig 243 Photograph of two surfaces of a macerated vertebral body sectioned in the sagittal plane The rig is seen in the lower part of the figure, the left half is seen in the upper part of the figure A large Schmorl's seen in spongiosa extending posteriorly from the vertebral plate A small Schmorl's node can be seen anteroinferior portion of the vertebral body (arrows)

period of growth It is unfortunate that detailed serial microscopic sections for the study of this problem are lacking

Schmorl, by carefully perforating the cartilaginous plates through the lateral wall of the vertebral body in a cadaver, and without the application of any special pressure, has induced disc tissue prolapse into the small cavities thus produced This prolapse appears to have resulted solely by reason of the intrinsic tension within the nucleus pulposus Similar experimental studies using laboratory animals have been carried out by Keyes, Compere, Lob, W Muller et al , but extrapolation of the results to human beings is hazardous because of existing anatomic differences (*e g* , the bony "epiphyseal plate" in the animal, p 8)

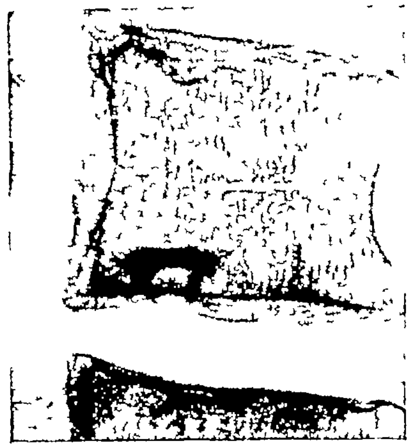


Fig 244 (left) Radiograph of a sagittal section of the lumbar spine Man, age 21 Two small Schmorl's nodes, one in the superior and one in the inferior portion, each of which exhibits delicate bony envelopes

Fig 245 (right) Lateral radiograph of a sagittal section of the lumbar spine Man, age 31 Marked sclerosis surrounding a Schmorl's node which protrudes into the vertebral body A smaller node protrudes into the body from above

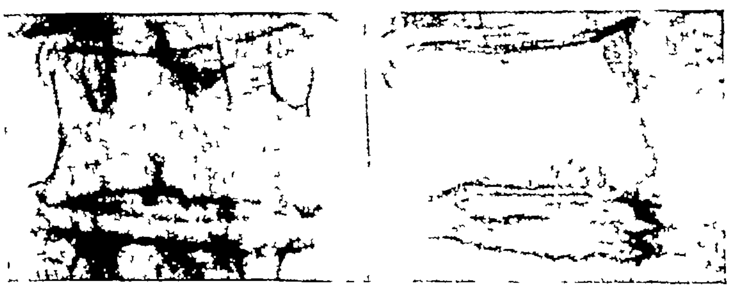
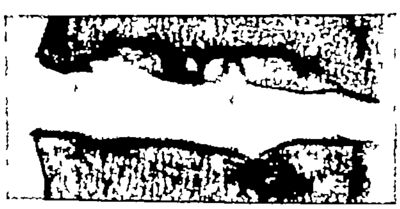
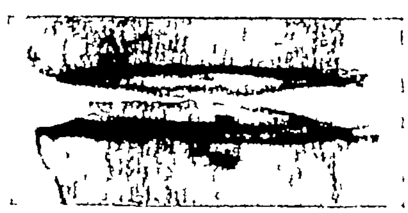


Fig 246 Radiograph of the midthoracic area of a woman, age 62 Anteroposterior and lateral views In the lateral view (right) a curvilinear area is seen within the vertebral body In the anteroposterior view (left) this is recognized as the thin sclerotic envelope surrounding a Schmorl's node





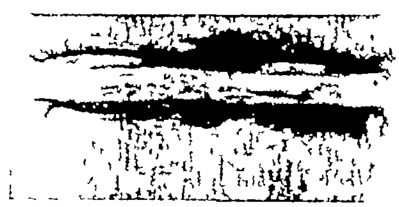


Fig 247 (left) Lateral radiograph of a sagittal section of a spine Man, age 27 Two Schmorl's nodes indenting the inferior surface of the upper vertebral body and a smaller node indenting the superior surface of the lower vertebra The condensation surrounding them represents the typical bony envelopes which often surround these nodes The cartilaginous rims show no changes

Fig 248 (center) Lateral projection of the thoracic spine Woman, age 89 Vertebral arches have been removed A small cartilaginous node has protruded into the inferior vertebral body and shows a thin bony envelope Small areas of calcification are seen in the prolapsed disc tissue

Fig 249 (right) Lateral radiograph of the spine of a man age 71, after removal of the vertebral arches Disc prolapse has occurred into the vertebral bodies and calcification has followed

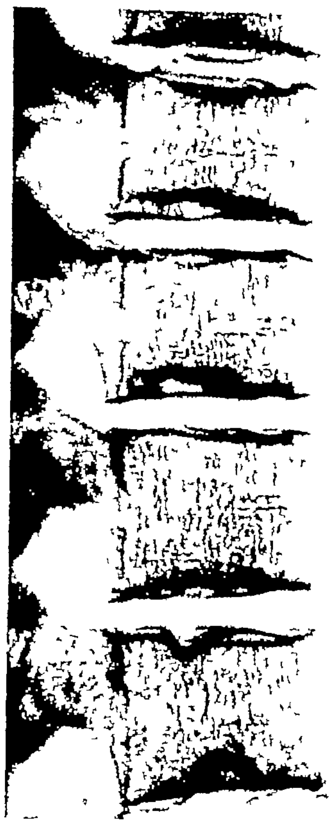


Fig 250 (left) Lateral radiograph of a sagittal section of the thoracic spine Man, age 52. Numerous irregular shadows are seen in the anterior portions of several of the vertebral bodies These represent sclerotic envelopes surrounding prolapsed fragments of disc tissue The rims are intact

Fig 251 (center) Photograph of a sagittal section of the thoracic spine Boy, age 16 Typical Schmorl's nodes are present Not all of the rims have completely united with the vertebral bodies and the intervening cartilages are still visible

Fig 252 (right) Lateral radiograph of the thoracic spine Woman, age 19. Schmorl's nodes indent the superior and inferior surfaces of nearly all the vertebral plates and are recognizable by the surrounding sclerotic bone envelopes The bony rims have already developed and have united with the vertebral bodies

When destructive processes within a vertebral body lie close to, or have affected, the cartilaginous plate, the development of disc tissue prolapse and the picture of the end-state is somewhat different Because of the bone destruction, a large area of the cartilaginous plate gives way, opening into the vertebral body (figs 256 and 257) and, because of the destructive process, the reactive changes of bone proliferation and the production of a bony barrier cannot develop (fig 258)

If a Schmorl's node is produced by one of the causes thus far discussed (congenital or acquired changes in the cartilaginous plates, or destructive changes in a vertebral body), the superimposition of the stresses of spinal function are sufficient to produce the necessary fissuring in the damaged cartilaginous plate There appears to be no doubt, however, that on occasion a single trauma may produce rupture of a cartilaginous plate which was until that moment entirely intact Traumatic lesions in adolescents tend to produce stellate or serrated tears in the cartilaginous plates (fig 326) The central area of a vertebral body may be compressed to such a degree that prolapsed tissue from the disc above may come into actual contact with prolapsed tissue from the disc below (fig 330) Other important relationships between trauma and the formation of Schmorl's nodes are discussed in another section (p 180) A rare specimen (fig 259) is represented radiographically in figure 260. a bullet that became embedded in a vertebra caused a prolapse of disc tissue into the vertebral body

Various writers have observed that, in addition to Schmorl's nodes developed as we have just described, small foci of cartilage proliferation (cartilage nodes) may appear on the surfaces of the cartilaginous plates facing the vertebral bodies (Putschar), independent of the prolapse of disc tissue These nodes are said to represent the proliferation of cartilage cells of the growth layer

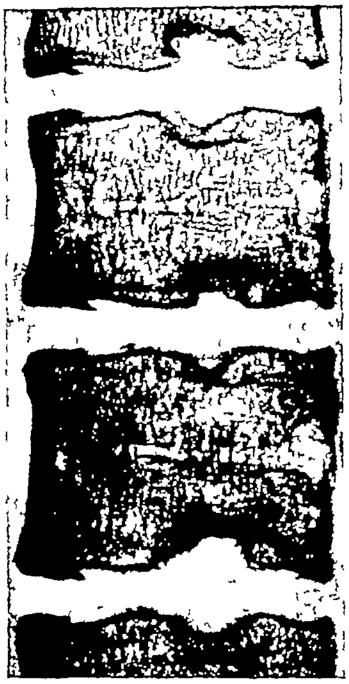


Fig 253 (left) Lateral radiograph of a sagittal section of the thoracic spine Man, age 20 Note the irregular indentations of the disc tissue into the vertebral bodies representing Schmorl's nodes surrounded by a delicate envelope The elevated bony rims which are visible on the anterior body edges are intact

Fig 254 (right) Radiograph of a sagittal section of the spine Man, age 51 Schmorl's nodes are present in all of the vertebral bodies The rather rare occurrence of two neighboring Schmorl's nodes beneath the superior vertebral plate of the lowermost vertebral body is shown (cf figs 239 and 247)

Fig 255 (left) Radiograph of the lower thoracic spine in a slightly oblique projection Woman, age 37 The intact rims of the vertebral plate surfaces appear to be somewhat elliptical The irregular shadows in the centers of the vertebral plate represent cartilaginous nodes

Fig 256 (right) Photograph of a sagittal section of a lumbar vertebra Rupture of the cartilaginous plate and prolapse of disc tissue into the body of the vertebra The spongiosa has been destroyed by an osteolytic lesion

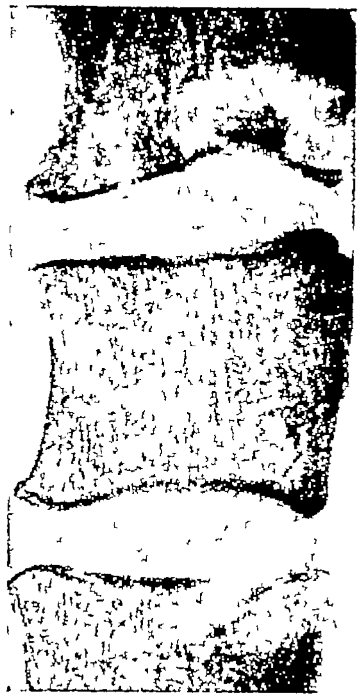




Fig 257 (left) Lateral radiograph of the lumbar spine Man, age 68 Disc tissue prolapse into the vertebral body, as seen in the previous illustration

Fig 258 (center) Radiograph of a sagittal section of a spine Metastatic carcinoma Since the metastatic process has destroyed the vertebral plates, the disc tissue has invaded the vertebral body

Fig 259 (right) Photograph of a sagittal section of a spine Man, age 32 A bullet in the twelfth thoracic vertebra has penetrated the body of that vertebra and has destroyed the cartilaginous plate This has produced a prolapse of the disc tissue into the vertebral body

Fig. 260 (below) Subject same as figure 259 (right) Considerable narrowing of the disc space has occurred due to the prolapse of disc tissue

(Michajlow and Tscherepnina) The possible relationship between these nodes (which never attain to any material size) and the "degenerative cartilage nodes" described by Schmorl and which are frequently found in extensive disc degeneration (osteochondrosis, p 163) needs to be clarified by further investigation

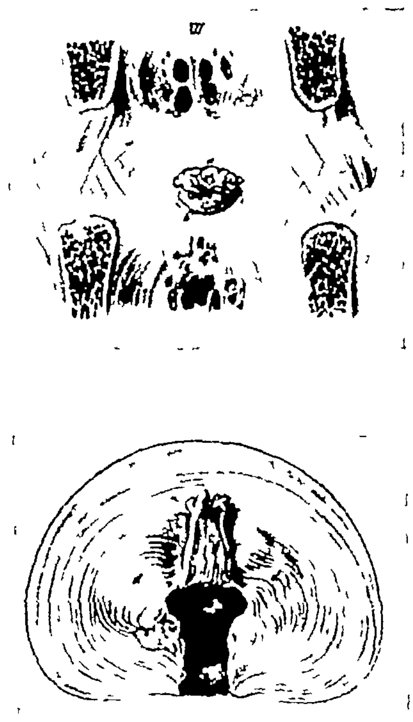
On the basis of his very large material, Schmorl reported on the frequency of the occurrence of Schmorl's nodes, and this study, which was anatomic, not radiologic, demonstrated their presence in 38 per cent of all spines examined Their occurrence is slightly greater in males (39 9 per cent) than in females (34 3 per cent), undoubtedly reflecting the greater stresses to which the spines of males are subjected Radiologists find Schmorl's nodes in only 13 5 per cent of all human subjects, indicating that the greater number of these nodes are not demonstrable radiographically The initial prolapse is so small that it does not produce any visible changes in the radiographic shadow of the vertebral body, and the loss of disc tissue occasioned by the prolapse is not great enough to bring about a demonstrable decrease in the height of the disc space Radiographic demonstration of the prolapse of disc tissue is possible only when the vertebral body, as a defense against the pressure on the spongiosa by the elasticity of the prolapsed tissue, has produced a bony barrier against such pressure (Schmorl, W Müller, figs. 240, 244 – 247, 252 – 254) Sometimes, there occurs calcification of the prolapsed tissue and the node thus becomes recognizable in the radiograph (figs 248 – 249)

The bony barriers surrounding the prolapse within the vertebral body can be demonstrated not only in the anteroposterior and lateral projections, but they may be recognized in oblique views In these, one sees on the elliptic superior and inferior surfaces, ill-defined zones of condensation having no connection with the posterior margins of the rims (fig 21)

Dieterich and W Muller have studied the regression of these fibrocartilaginous nodes in serial radiographic examinations The regression appears to begin where the disc prolapse has come to rest and when, in the absence of additional stimuli from elastic pressure, the sclerotic reactive process has undergone absorption In a later chapter (p 154 and 198), we will review the effects produced by multiple fibrocartilaginous nodes, especially in juvenile kyphosis, and the clinical manifestations of pain and functional disturbance which they may produce It is interesting to note that Schmorl's nodes were found in spines dating back as much as three thousand years, and uncovered in archeologic excavations (Rokhline, Roubachewa and Maikowa)

2. Posterior disc prolapse

Disc tissue may prolapse not only upward and downward but posteriorly into the neural canal and posterolaterally into the intervertebral foramina By means of serial examination, these various prolapses first described by Luschka were studied carefully by Schmorl (fig 261) The significant



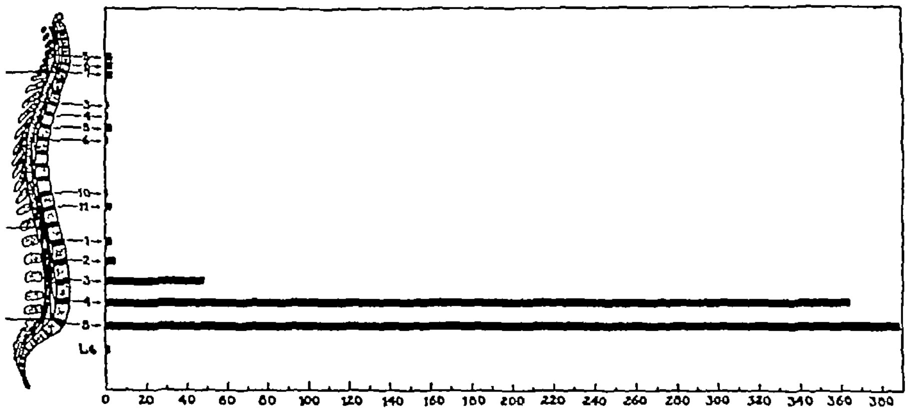


Fig 261 (left) Drawing by Luschka First known presentation of posterior prolapse of a disc Above posterior wall of the disc with the prolapsed disc fragment Below horizontal section of the disc with a fissure passing through the nuclear region posteriorly

Fig 262 (right) Schematic representation of 750 cases of prolapse of the disc (Adson)

clinical manifestations arising from posterior prolapse of disc tissue has only in recent years received the attention and excited the clinical interest that they deserve In a later chapter we will discuss this subject in some detail

In 1929 Andrae, with Schmorl's material at his disposal, produced the first statistical analysis of posterior prolapse of portions of disc tissue These occurred in 56 of 368 spines examined, *i e*, in 15 2 per cent of spines They were seen in 11 5 per cent of males and 18 7 per cent of females As many as seven posterior disc prolapses were found in a single spine, and in several there were two prolapses in the region of a single disc It is quite striking that, in this series, not a single prolapse was found in a person younger than 30 Study of the material of Schmorl's Institute shows that the most frequent location of posterior disc prolapse is in the lower thoracic and the lumbar spine and that they occur very rarely in the cervical region

The literature now contains articles on the results of clinical studies and these confirm the lumbar spine as the principal site of posterior prolapse (Adson, Barthel, Love, Raaf et al) Less common

Fig 263 (left) Photograph of a sagittal section of the thoracic spine Man, age 48 The disc space T 10—T 11 is markedly narrowed and a portion of the disc protrudes posteriorly into the spinal canal forming a posterior "Schmorl's node" Beginning ossification of the nucleus pulposus

Fig 264 (right) Photograph of the spine seen from behind after the removal of the vertebral arches Note the protrusion of Schmorl's nodes (arrows!) beneath the posterior ligament

Fig 265 Radiograph of a horizontal section of an intervertebral disc Cloudy calcification of the nucleus pulposus with extension posteriorly Nuclear prolapse into the vertebral canal Calcified posterior Schmorl's node

Fig 266 (right) Photograph of a section of the spine after removal of the vertebral arches Note the small, rounded ossifications on the posterior edges of two of the vertebral bodies These represent partial ossification of cartilaginous nodes Before maceration the two small bony nodules were connected by cartilage

Fig 267 (left) Radiograph of a section of the spine after removal of the neural arches Man, age 54 The ovoid shadow lying in an intervertebral space represents an ossified posterior Schmorl's node

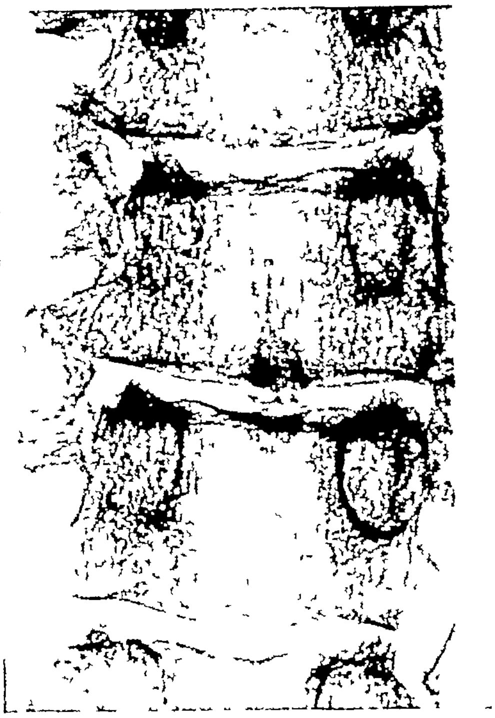


Fig 268 (right) Photograph of a sagittal section of a thoracic spine A small posterior Schmorl's node displaced somewhat upward lies between the vertebral body and the posterior longitudinal ligament (arrow!)

is the thoracic spine (Liedberg, Petit-Dutaillis et al), and the cervical spine is a very rare location (Chiasserini, Graeff, Liebdberg et al) This is shown clearly in Adson's diagrammatic representation (fig 262) The great frequency of posterolateral prolapse has been demonstrated irrefutably by Lindblom Although Andrae, in his study of Schmorl's material, found no posterior disc prolapses in persons younger than 30, their existence in clinical material has now been confirmed frequently Key and Wahren cite the case of a 12 year old who required surgery for disc prolapse

Fig 269 A large prolapse of the L 4—L 5 disc is displaced in a posterosuperior direction and lies behind the body of the fourth lumbar segment A laminectomy has been performed (illustration of Schachtschneider)

The anatomic features of posterior disc prolapse vary greatly In the majority of cases, they appear as small nodes lying beneath or beside the posterior longitudinal ligament and protruding into the neural canal (figs 263 and 264) They do not always lie at the level of the disc from which they have prolapsed, but may travel upward or downward to lie between the posterior wall of the vertebral body and the posterior longitudinal ligament or somewhat lateral to the latter (figs 265, 268 and 269) These small nodes may calcify or even ossify, thus becoming demonstrable radiographically (figs 266 and 267) Since the nodes are usually quite small, they do not, commonly, produce subjective or objective findings, and Andrae was able to demonstrate this type of posterior prolapse only in his serial examinations of the spines of cadavers As early as 1929, however, Schmorl called attention to the possibility of cord lesions being produced by posterior prolapse of disc tissue Since that time, pathologicoanatomic studies and clinical investigation have widened considerably our knowledge of the origins and the clinical manifestations of this lesion

Posterior disc prolapse is, essentially, a lesion of the disc and the ligamentous apparatus Posterior or posterolateral fissuring affecting the annulus fibrosus and extending posteriorly is the prerequisite

for posterior disc prolapse (fig 270) The general loosening of the structure of the disc produced by these fissures, aggravated by spinal movement and functional strain permits the backward displacement of fragments of disc tissue, and the posterior wall of the disc, covered by the posterior longitudinal ligament begins to bulge into the neural canal or into the intervertebral foramen laterally,

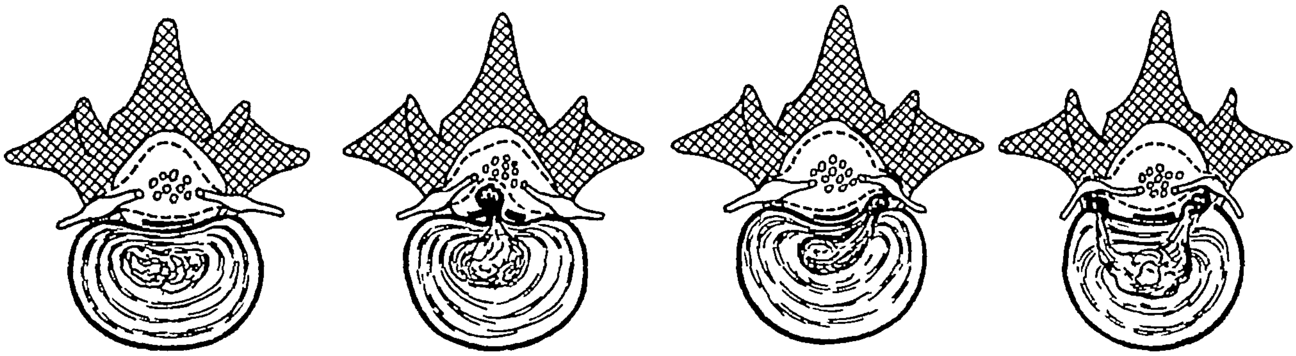
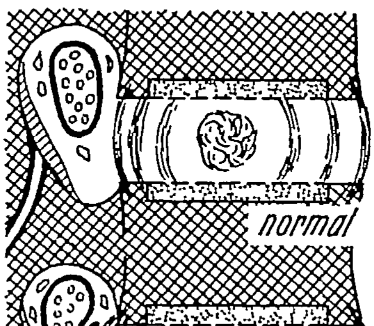


Fig 270 Diagrammatic representation of the various forms of the posterior prolapse of the disc (A) the normal disc (B) central prolapse with rupture of the posterior longitudinal ligament (C) posterolateral prolapse toward the intervertebral foramen with pressure on the nerve root (D) bilateral posterior prolapses which may have originated either simultaneously or consecutively

depending on the direction of the pressure resulting from movement, and thus there develops a protrusion of the disc with bulging of the posterior wall (fig 271) In the lumbar region the nerve fibers on the anterior wall of the neural canal (see p 16) are involved and there appears the clinical picture vaguely called "lumbago," without segmental radiation corresponding to the nerve roots of the involved segment This "internal disintegration" of the structure and normal function of the disc tissue results in a "loosening of the motor segment," and this is an essential cause of the appearance of lumbosacral pain (p 154) The small vertebral joints and the ligaments of the involved motor segment undergo excessive strain as a result of the loosening of the disc and the attempt of the muscular system to compensate for the loosening by muscle spasm is also a cause of pain



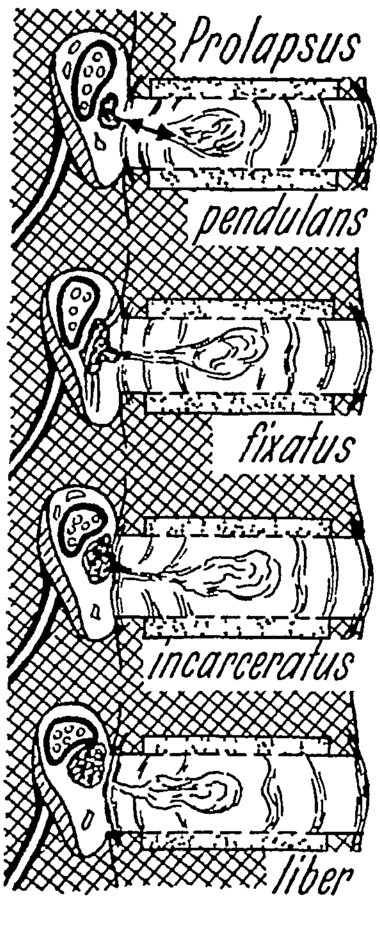


Fig 271 Schematic representation of the various forms of posterior prolapse of a disc Left bulging of the posterior portion of the disc Right (from above downwards) recurrent prolapse, fixed prolapse, incarcerated prolapse, and free prolapse (sequestration of a disc)

When the fissuring process has ruptured the disc substance posteriorly or posterolaterally, thus opening the way for prolapse of sequestrated portions of the disc into the neural canal or into the intervertebral foramina, then, and only then, can true prolapse occur (fig 271) Experimental studies carried out on cadavers indicate that posterior prolapse (as a "recurrent prolapse") may occur with protrusion of disc fragments into the neural canal with certain movements, and their return to the disc space with others (Heine, Schachtschneider) This protrusion and reduction may be demonstrated, sometimes during surgery,

by flexion and hyperextension of the spine When contraction of the fissure makes a reduction of the prolapse impossible, an "incarcerated prolapse" has occurred The recurrence of symptoms and findings may be explained by the release of the incarceration and a repetition of the whole series of events If the formation of adhesions by local irritation prevents the reduction of the prolapse, a "fixed prolapse" is said to have occurred It may happen that the prolapsed tissue loses all connection with the disc and lies in the peridural space, where it may migrate upward or downward between the dura mater and the posterior vertebral wall, and this is known as the "migratory" or wandering prolapse Rarely, the prolapsed tissue may penetrate the dura, to float freely in the cerebrospinal fluid, and this is called "intradural prolapse" In addition to these quite distinct types of posterior disc prolapse, there are combination forms which are anatomic variants, but which also produce the characteristic clinical findings of posterior disc prolapse (figs 271 and 284, cf p 154ff)

In recent years we have come to realize that the basic factors concerned with fissuring and the ultimate prolapse of disc tissue are essentially the aging process, degenerative changes, and the general wear and tear to which the disc is subjected (cf chapter IV C 1) In 1858 Luschka described a posterior recess or pocket in the nucleus pulposus which he considered, apparently, a normal extension of the nuclear space and, thus, a possible pathway for disc prolapse This interpretation is illustrated in figure 261 Schmorl, who first thought the posterior prolapse to be an accessory nucleus pulposus, subsequently explained the facts on the basis of extensive histologic studies which he carried out in co-operation with Andrae They found that, in every case, there were destructive processes involving the annulus fibrosus and consisting largely of degenerative changes The view of Schmorl's school then became that disc prolapse results essentially from degenerative changes and the superimposed functional strains of everyday life, and only rarely from the effects of a single trauma This view has been confirmed by numerous histologic studies, notably by Boemke, Lewey, Lindblom, Ricard and Girard, Schachtschneider, Siegmund et al It seems clear, then, that in the vast majority of cases the tissue changes observed must be construed as the effects of wear and tear on the disc tissue These consist primarily in dehydration of the nucleus, produced by the aging process (p 16) and affecting chiefly those special areas which are subject to the greatest functional strain (the lumbar and cervical regions) "Posterior prolapse of the disc" is to be considered, therefore, as part of the state of "chondrosis" which will be described in detail in a subsequent section (chapter IV C 1) Reimers, basing his opinion on histologic studies, believes that the dehydration of the nucleus is preceded by chondrosis dessicans in the cartilaginous plate with disturbance of the nutrition of the disc tissue He believes that this sequence of events is necessary for sequestration of disc tissue and the prolapse of the sequestrated fragments by daily functional strains (cf p 158) Ewald's theory of allergy as a contributing factor has not been substantiated Pette thinks that there are other intervening mechanical factors which are the result of dynamic actions Among these he included congestive changes in the lymphatic and venous system of the nerve roots and the collagen diseases It is of interest that disc prolapse is especially frequent in association with chondrodystrophy (Lindemann, Kuhlendahl) The causes of disc chondrosis are quite obscure and further study is needed most urgently Both anatomic studies and observation during surgery have established quite clearly that the prolapsed tissue contains not only portions of the nucleus pulposus but fragments of the annulus fibrosus and of the cartilaginous plates For this reason the designation "prolapse of the nucleus pulposus" should be avoided, and "disc prolapse" should be employed instead

In horizontal sections of the discs, fissuring is seen to occur in two principal forms The first of these consists of fissures which are concentric and which are associated with semilunar areas of disintegration of the structure of the annulus fibrosus These are responsible for certain pathologic conditions as, *e g*, senile kyphosis (chapter VI A 3) But there occur also fissures which pass across the layers of the annulus at right angles to the course of the fibers These fissures, extending posteriorly or posterolaterally from the center of the disc, pave the way for prolapse of the disc tissue as described in an earlier section (p 144)

Discs which show marked "chondrosis" and the disintegration of large areas rarely participate in posterior prolapse The explanation of this seems to be that the inherent tension of a certain

amount of unaltered elastic disc tissue seems to be necessary for the expulsion of small fragments The period required for complete posterior prolapse varies a great deal, but in general it will be a period measurable in years

Histologic studies indicate that in many cases the initial fissuring and disintegration occurs in an age period when the physiology of aging does not serve to explain the disc lesion There is a good deal of evidence that symptoms appeared during the juvenile period, before the completion of growth (*i e*, before age 25) Moreover, the not infrequent finding of an isolated lesion, confined to a single disc, suggests that there may be special etiologic factors involved Perhaps additional study of chondrosis dessicans of the cartilaginous plate, as postulated by Reimers (p 145) may offer some explanation Be this as it may, the etiology and the pathogenesis of chondrosis dessicans, a disease of juvenile cartilage, is poorly understood, and we do not know whether it is of traumatic origin or results from a congenital variation Certainly the strains imposed on the cervical and lumbar discs by the physiologic necessities of daily life play an important role in the development and the progress of disc prolapse in these regions These unremitting stresses produce fatigue lesions in the disc tissue, resembling the so-called march fracture or fatigue fracture of bone, when the effort demanded surpasses the functional capacity of the disc We must admit, however, the intervention of other factors if we wish to explain why in one case fissuring is concentric with little or no tendency to produce prolapse, while, in another, prolapse will be induced by transverse fissures We do not know the answers to these questions and, in particular, we do not understand the relationship of "initial trauma" which may initiate the process during the juvenile period In spite of the extensive anatomic and histologic studies heretofore made, and the clinical studies and observation during surgical exploration, we simply do not know the origins of the changes which precede disc prolapse, and additional pathologic and anatomic studies are badly needed The theory that disc prolapse represents man's tribute to the upright position lacks satisfactory substantiation

Even if it be admitted that the pathogenesis of disc lesions which precedes prolapse is largely a process of dehydration, degeneration, and the wear and tear on the disc tissue, the question of the role of trauma remains controversial It is plain that much effort has been expended in an attempt to distinguish, histologically, between congenital disc lesions, and those which may be of traumatic origin, and this problem is not only of scientific interest but is of great importance from the economic and the medicolegal standpoints Unhappily, neither the study of autopsy specimens nor of tissue removed surgically, has permitted a satisfactory answer The difficulty lies in the fact that both autopsy examination and surgical exploration commonly occur long after the accident which might be the causative factor Moreover, in the case of posterior prolapse after violent rupture of a perfectly sound disc, degenerative changes appear rapidly in the detached fragment making an objective appraisal of the factor of trauma almost impossible

Since patients with posterior disc prolapse (p 154) nearly always relate their symptoms to some antecedent trauma, an extensive literature dealing with this problem has developed The traumatic prolapse of disc tissue into the neural canal resulting in death by section of the cord has been described in a few unusual cases (J Böhler, Jenson, Middleton and Teacher, Mixter and Ayer, Volkova et al) However, in not only these fatal cases, but in those in which a violent trauma was followed at once by the appearance of a posterior prolapse syndrome, the problem of the prior integrity of the disc remains to be solved (cf chapter IV E) The literature indicates that, in from 45 per cent to 85 per cent of cases, there exists some relationship between trauma and posterior disc prolapse (Barr, Love and Walsh, Raaf et al) It is only rarely that trauma can be accepted as the sole causative factor involved and, commonly, it will be a question of an accidental exacerbation of a pre-existing lesion Usually, it will be some trifling action of everyday life, such as, sneezing, getting into bed or bending to pick up an object, or it may be an habitual occupational action of lifting a weight, turning a wheel, or suddenly straightening up after bending These are the types of trauma which ordinarily precede the onset of pain and the appearance or the exacerbation of the disc syndrome (p 154) There is a quite extensive literature dealing with this difficult question and among the numerous writers we cite Baumann, Bürkle de la Camp, Friberg, Günther, Heine (experiments on cadavers), Jaeger, Jaeger and Grill, Junghanns, Künzel, Kuhlendahl, M Lange, Lob, Mock, Perazzini, Reisch-

auer, Schachtschneider, Siegmund, Stimpfl, Teneff, Uebermuth, Volkmann, Williams, Wilson and Straub, and others Keller has written a monograph in which he has summarized the difficulties encountered in the evaluation of the relation of disc prolapse to the stresses of military service, prison life and the edema of malnutrition

Baker, Reischauer, Wilson, and others have described instances of posterior disc prolapse following spinal puncture in which the needle was inserted too deeply, thus damaging the intervertebral disc Such cases are clearly of traumatic origin For this reason we believe that discography should not be undertaken too lightly (p 148)

At present we are able to recognize posterior disc prolapse at autopsy and, in life, by various clinical and radiographic methods to be described later (p 148) Certainly many errors have been made and it is very probable that many so-called tumors found in the anterior wall of the neural canal and described as enchondromas, chondromas and fibrochondromas were, in fact, posterior Schmorl's nodes (Alpers with Grant and Yaskin, Bucy, Puusepp, Zlaff, Zeno and Cames et al)

Differentiation between true disc prolapse and the various space occupying lesions of the neural canal and the intervertebral foramina is not difficult at autopsy, but is frequently impossible clinically Many lesions which had been believed to be extramedullary cord tumors were found at autopsy (or at surgery) to be posterior disc prolapses (Schachtschneider et al) Busch and Christensen think that 14 per cent of all lesions diagnosed as cord tumors and 36 per cent of those called extramedullary tumors are, in fact, posterior disc prolapses Occasionally a nodular varicosity developing in the neural canal may simulate posterior disc prolapse (Bär and Haslinga, Bartschi-Rochaix) Cord tumors, and especially hourglass tumors, which involve the intervertebral foramina must be differentiated from disc prolapse Hypertrophy of the ligamentum flavum may produce narrowing of the neural canal and, especially in hyperextension, a localized bulging of the ligamentum flavum may intrude into the canal (Berguignon and Caillon, Dickson with Carnegie and Twort, Hart, Iff, Love and others) These conditions must be differentiated from disc prolapse and it should be observed that the importance and the frequency of occurrence of hypertrophy of the ligamentum flavum was probably overstressed in the period when surgeons had not thoroughly familiarized themselves with the normal appearance of these structures (chapter I D)

Osteophyte formation on the posterior margins of the vertebral bodies is not an infrequent feature of the syndrome of posterior disc prolapse This is seen much less frequently than on the anterior and lateral margins, where it is quite characteristic of spondylosis deformans (chapter V) All bony spurs on the vertebral margins depend for their formation on certain lesions of the disc tissues, and it may be that disturbances in the posterior portions of the disc provoke osteophyte formation on the posterior vertebral margins (This hypothesis has been confirmed by animal experimentation conducted by Keyes and Compere) Minor bony fringing of the posteromedial vertebral margins rarely produces any narrowing of the neural canal and is not commonly associated with pain or other clinical manifestations Posterolateral osteophyte formation, on the contrary, is quite capable of radicular compression (by narrowing the intervertebral foramina) and may do so alone or in conjunction with posterior prolapse (p 154) These posterior osteophytes are sometimes visible in the radiograph (figs 272 and 273)

As we have remarked earlier, disc prolapse in the cervical region occurs very infrequently, and differentiation between it and the narrowing of the intervertebral foramina by osteophytes arising from the small joints of Luschka presents serious difficulties (see also chapter III N, figs 274 and 275) This is an unexplored field in which there are very great anatomicopathologic possibilities (Duus and Kahlau)

In the conventional x-ray examination of the cervical spine it is very rare to recognize a posterior disc prolapse and this is possible, ordinarily, only if the prolapsed material has undergone calcification or ossification (Kovács, fig 267), a change that requires a considerable lapse of time for its occurrence Occasionally all or a part of a calcified disc is displaced backward (fig 265) Osteophyte formation on the posterior margins of a vertebral body indicate the presence of a lesion in the posterior portion of the disc and, as already mentioned, may be an indication of posterior prolapse Additional radiographic findings, not in themselves diagnostic but which considered in conjunction with other

Fig 272 Lateral radiograph of the lumbar spine Woman, age 40 Chondrosis of the L 4—L 5 disc Narrowing of the disc space, narrowing of the intervertebral foramen, and osteophyte formation on the lower margins of the fourth lumbar segment anteriorly and posteriorly

Fig 273 Lateral radiograph of the thoracolumbar spine Man, age 28 Schmorl's node in the posterior aspect of the 12th thoracic vertebra with narrowing of the intervertebral space and with osteophyte formation There is also a rather large Schmorl's node in the posterior aspect of T 11

changes increase the likelihood of a correct diagnosis, may be obtained by careful observation of the width and the outline of the disc space and "functional radiography" (Junghanns) We have referred to this in several other places (pp 21, 22, 130, 154, 157, 160 and 178, Junghanns)

Difficulties encountered in the direct recognition of posterior disc prolapse led to the development of new technics for roentgen examination, including myelography and discography employing various gases and radiopaque media (fig 276), and these various methods have their partisans (Albrecht and Dressler, Begg and Falconer, Boult with Kiernan and Childe, Bradford and Spurling, Brocher, Bronson, Buchholz and Häussler, Bücker, Busch, Cramer, Echlin, Friberg and Hult, Gillespie, Glorieux, Haussler, Hamptom and Robinson, Hellmer, Hofmann, Junghagen, Kehrer, Knutsson, Mixter and Ayer, Murphy, Reinhardt and Panter, Ritter, Säker, Schoen, Soule with Gross and Irving, Tiwisina and others) However, the radiographs give only negative images in posterior prolapse, and these methods are not practical in small lateral prolapses According to Friberg nodules of less than 8 mm diameter are not visible in a myelogram Kloss thinks that so-called "functional myelography" will yield better results Discography (direct injection of a radiopaque material into the disc) permits demonstration of the fissures and their connection with the peridural space (cf figs 286—292) and the radiographic findings are comparable to those observed in the serial sections which Junghanns made of the spines of cadavers at Schmorl's Institute Unfortunately, the introduction of a needle into the disc tissue of a living subject is not without hazard and may, possibly, produce prolapse into the neural canal along the course of the needle (p 146) Also, it is possible that in a disc with changes predisposing to prolapse, the pressure of the injected material may initiate a posterior prolapse or may displace a detached fragment temporarily at rest Nevertheless, the experimental work of Lindblom, later amplified by Fischer, deserves careful study (Asang, Bombelli, Buffard and Ecoiffier, Cloward and Buzaid, Erlacher, Grassberger and Seyss, de Haene, Percy, Perl, Roman and Ydén, Saruchankan and Cherobjan, Seyss, Sieber, Walk, Witt et al)

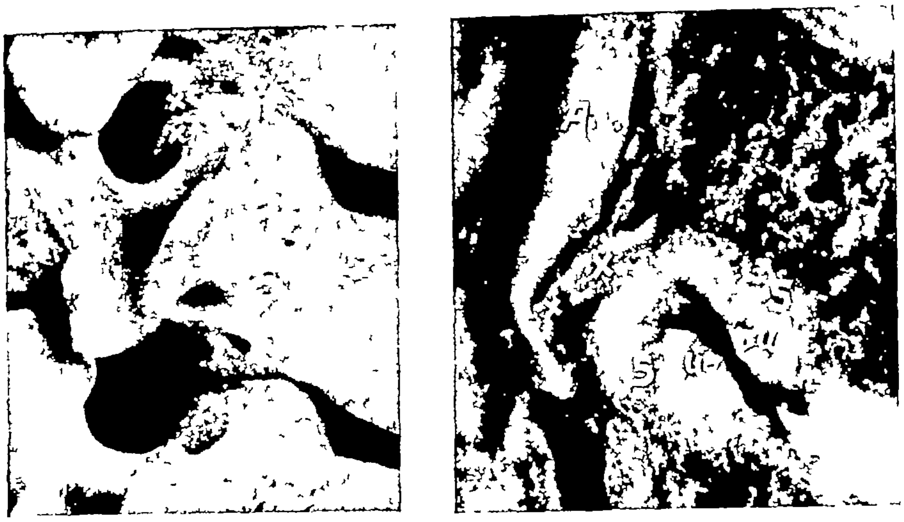


Fig 274

Fig 275

Fig 274 The small joints of Luschka in the cervical region (from Krogdahl and Torgersen) Left Osteophyte formation (x) (dried specimen) Right Constriction of the intervertebral foramen and displacement of the vertebral artery (A v) by osteophytes

Fig 275 Part of an oblique projection of the cervical spine Man, age 56 Marked osteophyte formation involves the small joints of Luschka between C 5 and C 6 leading to narrowing of the intervertebral foramen

The difficulties of differential diagnosis in cases of posterior disc prolapse do not arise solely from the presence of foreign elements in the neural canal or in the intervertebral foramina (p 125) It is possible that narrowing of the foramen may be the sole cause of the presenting syndrome supplemented, perhaps, by prolapse of a fragment of disc tissue Duus and Kahlau, among others, have called attention to this possibility citing numerous anatomic, pathologic, and neurologic investigations Their opinion, however, has been disputed by Junghanns, Reischauer and others For a clear comprehension of the problem of posterior disc prolapse one must take care not to consider only the prolapse, or the narrowing of the intervertebral foramen, or the osteophyte formation on the posterior margins of the vertebral bodies and the joints of Luschka Each of these concerns a part of the motor segment (chapter I H, fig 41) and all are so closely interrelated that a disturbance of one affects all The clinical onset of pain (p 154), therefore, may be based on a minor degree of prolapse, diminution of the caliber of the intervertebral foramen and loosening of the motor segment According to Frykholm, radicular pain in the cervical region may be caused by deformity of the dural sac or by narrowing of the dural sheaths, and may manifest itself by the pain syndrome of posterior disc prolapse Fineschi describes a radicular compression resulting from narrowing of the intervertebral foramen in a transitional lumbosacral vertebra and a posterior prolapse Gillespie has described an identical case

Fig 276 Lateral radiograph of the lumbar spine after injection of opaque material into the spinal canal Man, age 30 Note the posterior displacement of the opaque column at the level of the fourth intervertebral space representing a disc prolapse Confirmed surgically.

The presence of a fragment of disc material in an intervertebral space and its progress toward the posterior wall of the disc space does not necessarily result in the formation of a posterior prolapse The migrating fragment of disc tissue, for one reason or another, may come to rest before it has entered the epidural space For example, a disc fragment whether pedunculated or free (sequestrated disc) may be fixed in position by infiltration by connective tissue Further migration may be prevented by the loss of the internal tension of the nucleus pulposus, so necessary

for the continuation of pressure Muscle spasm, which nature produces as a defense mechanism against pain, and therapeutic immobilization carried out for a like purpose, may relieve the functional strain sufficiently for healing of the disc fissures and for fibrous fixation of the prolapsed tissue This represents the so-called "spontaneous cure" of a prolapsed disc Anatomic cure by fibrous tissue proliferation, calcification, ossification or cicatrization may intervene in all the various stages of the development of disc prolapse, even when the detached fragment has penetrated the epidural space Such "functional stabilization" may occur also if after cicatrization of the disc fissures, the elastic pressure inherent in the disc ceases to exert itself against the detached fragment This, unfortunately, does not

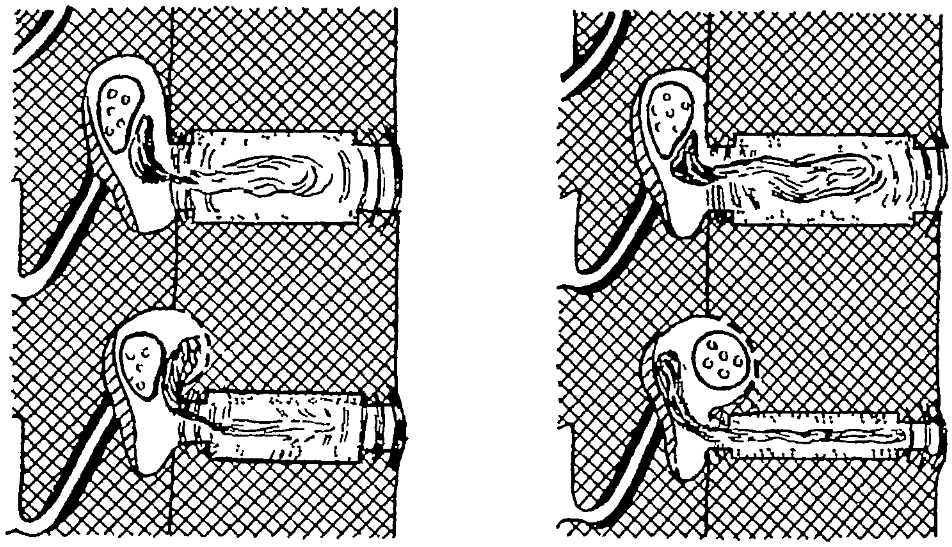


Fig 277 Spontaneous healing of root compression Left Displacement of the prolapsed fragment (Burns & Young 1947) Right Displacement of the nerve root which escapes the compression (Duus & Kahlau 1948)

necessarily end the subjective complaints Such stabilization will depend on the sequelae which follow the degree of spinal rigidity achieved, the functional status of the affected motor segment and the size and location of the prolapsed fragment We do not know whether the herniated portion of disc tissue is capable of growth and we lack completely histologic evidence of reactive proliferation around the prolapsed fragment If these possibilities exist, increase in the volume of a prolapsed fragment which lies in a critical position may lead to progressive increase in the subjective symptoms even when the internal tension of the disc plays no part It is possible, too, that the osteophytes on the posterior margin of the vertebral bodies may serve to block the migration of the detached fragment and this represents an additional method of "anatomic cure"

Radicular pain, so frequent with lateral disc prolapse, may, under certain circumstances, disappear even when the prolapse persists and continues to develop, this is because of the destruction of the involved root On page 155 we will discuss this in some detail On this thesis rest the observations of Friberg, Albrecht, and others, according to whom, nerve root disturbances persist in many cases in spite of the surgical removal of the prolapsed disc tissue Histologic studies of nerve roots damaged by compression by prolapsed discs have been carried out by Duus, Lindblom and Rexed Sprung believes that the prolapsed tissue interferes with the circulation of the cerebrospinal fluid with resulting metabolic disturbance of the nerve roots

Radicular pain, unhappily, usually accompanied by irreversible motor disturbance, is not the only "cure" mechanism of the painful phenomena of disc prolapse In a case of disc prolapse, Burns and Young observed the passage of the disc fragment to a position anterior to the nerve root If the position of the spine is favorable, the nodule of disc tissue may excavate for itself a bed in the posterior wall of the vertebral body, thus obviating all possibility of root pressure (fig 277) Duus and Kahlau have shown that the nerve root, by moving anteriorly into a gradually enlarged intervertebral foramen, may escape from compression by the prolapsed fragment or by osteophytes (fig 277), but Reischauer expresses doubt as to the correctness of this theory

It is conceivable that the symptoms of root compression in certain cases may steadily decrease and finally disappear, because of reduction in the volume of the prolapsed fragment, a reduction which by atrophy and dessication is possible According to Lindblom and Hultquist, decrease in the volume may be produced by infiltration of the fragment by vascular and connective tissue They base this hypothesis on histologic studies which were inspired by the earlier work of Schmorl and Junghanns (p 169) on the vascular connective tissue infiltration of the intervertebral discs, and the more recent observations of Conventry with Ghormley and Kernohan, and those of Eckert and Decker

The "adaptation" of the prolapsed fragment to its surroundings may cause the disappearance of the phenomena of root compression and thus lead to the "cure" of the disc prolapse or, rather, to the "cure" of the radicular pain This is possible, however, only when the prolapsed fragment is soft and is composed largely of nuclear tissue Under these conditions it is conceivable that the nodule of disc tissue may flatten itself against the bony structure and fix its position, thus no longer exercising pressure on the nerve root

The clinical signs of posterior disc prolapse, its diagnosis and its treatment will be described on page 154

3. Anterolateral disc prolapse: "marginal infraction"

Anterolateral disc prolapse has been considered as a rarity, but Schmorl's posthumous publications have offered evidence as to the frequency of its occurrence The disc fragment may insinuate itself between the wall of the vertebral body and the anterior longitudinal ligament and may even penetrate the ligament The detached fragment may migrate upward or downward between the vertebral body wall and the anterior longitudinal ligament This form of disc prolapse is of little clinical importance Bourdillon has described a case in which the prolapsed disc fragment was lodged in the muscles of the neck According to Martens, eccentric prolapse may be a causative factor in scoliosis Kemmler describes anterior disc prolapse, due to trauma, occurring in the cervical spine Employing discography, Cloward has demonstrated anterior disc prolapse and believes that patients with such a syndrome suffer back pain without the radiation associated with root pressure He thinks that many poor surgical results are explained by the presence of unrecognized anterior prolapse (cf Seyss)

The prolapse of disc tissue in an oblique direction and associated with marginal infraction is of considerable practical importance (cf p 97) In his last paper, published posthumously, Schmorl gave a comprehensive description of this form of prolapse (figs 269—273), and Niedner of Schmorl's Institute has described it in some detail, investigating and presenting diagrammatically the forces necessary for the production of this type of prolapse

With the combination of the stresses of everyday life and the degenerative changes occurring in the cartilaginous plate, the disc tissue may penetrate the bony trabecular network and prolapse into the vertebral body This usually occurs at the junction of the cartilaginous plate and the bony rim where the rim rises steplike from the

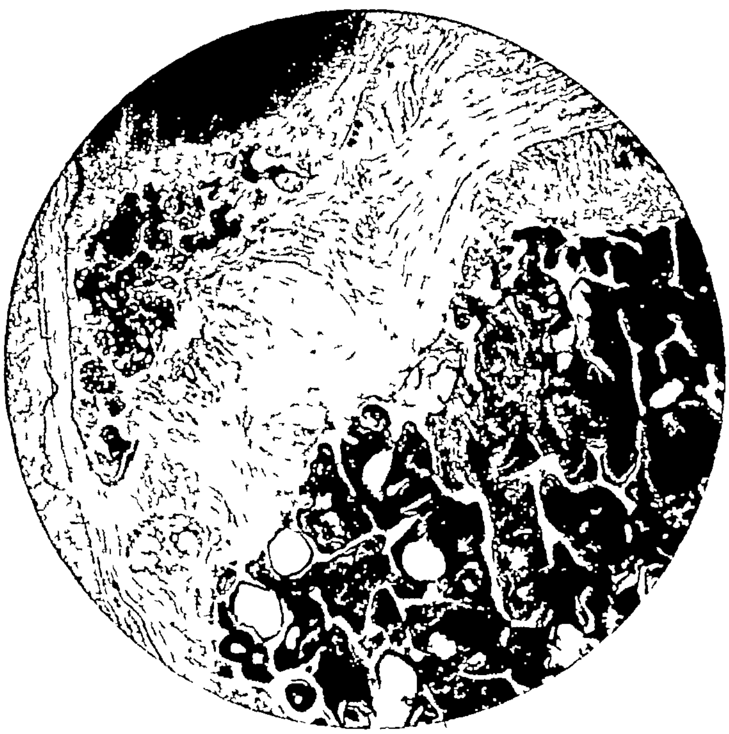
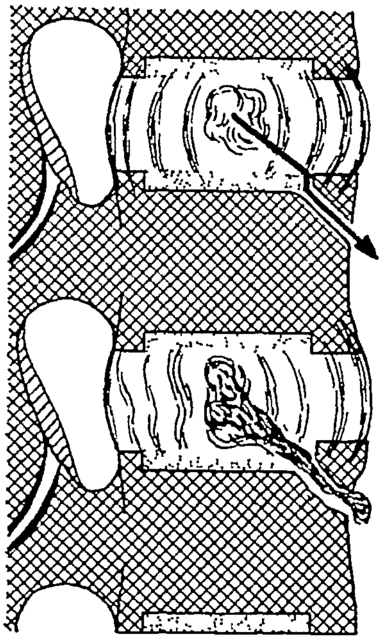


Fig 278 Microphotograph of a sagittal section through an anterosuperior body edge Wedge-shaped fragment of the vertebral body severed by prolapsed tissue The disc tissue has invaded the spongiosa through a fissure in the ventral portion of the cartilaginous plate

cribriform subchondral plate, these changes resemble those arising in the vascular channels of the cartilaginous plate The forces involved (Schmorl) determine the path of the prolapsed tissue, which migrates obliquely toward the outer vertebral surface (figs 278—280) This migration produces a fissure which severs a fragment of the edge of the vertebral body The fissure thus produced contains disc tissue and proliferating cartilage tissue resembling that found in the cartilaginous nodes Callus formation may occur on the opposing margins (fig 280) Niedner measured these detached vertebral body edges and found them to be larger than the normal bony rims Usually the detached rim fragments are seen involving the anterosuperior margins of the vertebral bodies and



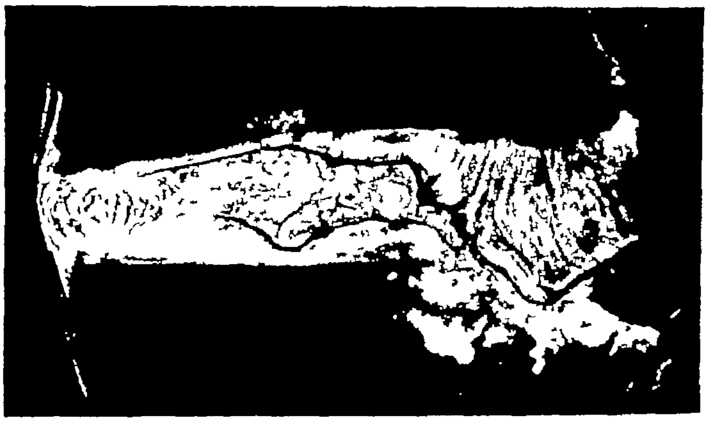


Fig 279 (left) Schematic drawing of the process of the separation of the vertebral edge The disc tissue undermines the vertebral rim and separates a fragment of it

Fig 280 (right) Slightly enlarged photograph of a sagittal section of a disc The disc tissue has infiltrated between the cartilaginous plate and the rim, has moved forward in an antero-inferior direction, and has severed a wedge-shaped fragment of the vertebral body Numerous areas of cartilage proliferation are present in the vicinity of the infraction The annulus fibrosus has been torn off the rim

only rarely do they occur at the anteroinferior margins (Niedner, Schmorl, Böhm, see fig 417) Their common location is in the lumbosacral portion of the spine Schmorl has described similar marginal infractions occurring on the lateral margins Lesions of this type may be found in multiple lumbar vertebrae in the same spine In the examination of 400 lumbar spines, Schmorl found 20 marginal infractions In most of them the disc showed continuous fissures extending obliquely from the nucleus pulposus to the site of infraction (Hammerbeck, fig 282) and Schajowicz has described basophilic degeneration in this area

The tissue of the annulus fibrosus, prolapsing into the oblique fissure gradually undergoes various processes of reconstruction The abnormal mobility of the detached edge fragment tends to break up the prolapsed tissue, and with cartilage proliferation a nearthrosis may develop (Schmorl) In the clinical and radiologic literature these

Fig 281 A lateral radiograph of a sagittal section of a spine. Woman, age 22 The anterosuperior edge of the fifth lumbar vertebra has been detached The triangular detached fragment is separated from the vertebral body by a smooth cleft which widens above The disc tissue is located in the cleft

detached triangular fragments of the vertebral margin (easily seen in the radiograph, figs 281 and 283) have been called "persisting vertebral body epiphyses" (Hanson, Janker, Joisten, Meyer and Rodier, Michajlow and Tscherepnina, Sorrel et al), but Junghanns has demonstrated the incorrectness of this thesis with comparative x-ray studies of the spines of cadavers

Fig 282 (left) Photograph of a sagittal section of the lumbosacral spine Woman, age 72 Severance of the antero-superior body edge of the fifth lumbar vertebra with a distinct fissure in the disc

Fig 283 (right) Radiograph of the preparation seen in figure 282 Dislocation of the detached edge fragment

After review of the literature (Böhmig and Prevot), Janker, Joisten, Reisner, et al) and after clinical investigations and extensive histologic studies, both Schmorl and Niedner reached the same conclusion as Junghanns, and their conclusions are supported by Hellstadius, Hetzar, Lenarduzzi, Mardersteig, Raspe, Schulze et al It is possible that these marginal infractions produce no clinical manifestations unless there is a concomitant disturbance of the disc resulting in a loosening of the motor segment For a detailed bibliography on this subject see Leger

4. Clinical significance of disc tissue prolapse

Prolapse of a portion of disc tissue cannot occur without alteration of the function of the disc or without reactions in the various portions of the affected motor segment A rather large prolapse leads, commonly, to decrease in the height of the disc space, frequently demonstrable radiographically (chapter IV B 2) Sometimes, in order to retain their normal thickness, the discs swell as they do when pressing into osteoporotic vertebral bodies (p 130), but this is possible only in the absence of degenerative changes in the disc tissue In rare cases and only if the prolapse is sufficiently small to permit proliferation to compensate for the tissue loss, the intervertebral space may retain its normal height Since the proliferating tissue usually has a tendency to shrink, this maintenance of height is of rather rare occurrence and, in general, the loss of disc tissue results in a decrease in the vertical diameter of the intervertebral space which is frequently demonstrable in the radiograph

Prolapse of disc tissue may be followed by two quite different phenomena The fissures in the annulus fibrosus and the space left by the prolapsed fragment may be infiltrated by vascular and connective tissue with resulting rigidity and decreased mobility of the affected segment (fibrous rigidity, chapter VII B 3) On the other hand, progressive degenerative changes and increasing disintegration of the disc tissue may be followed by an increased mobility between the vertebral bodies and a so-called "loosening of the motor segment "

In the majority of cases the prolapse of disc tissue into the vertebral body (Schmorl's node) is followed by limitation of motion, since vascular and connective tissue can extend readily into the affected disc space. If a Schmorl's node develops and leads to destruction of the growth zone in the juvenile period, spinal mobility will be affected. The sequelae of adolescent kyphosis will be discussed in chapter VI A 2. If disc tissue prolapses into the epidural space, there is the possibility of healing of the disc rupture with resulting limitation of motion as discussed on page 150 and proven by Andrae's histologic studies.

Fissure formation in the annulus fibrosus, always associated with posterior prolapse of disc tissue, not only leads to relaxation of the normal, firm, body-disc solidarity, but in a "loosening of the motor segment." Although healing (p. 150) may occur, usually the loosening persists and is of much significance in the consideration of a treatment (Junghanns). Not only does it appear as a sequel of posterior disc prolapse, but accompanies all of the changes which affect seriously the disc structure. The low-back pain which persists after the surgical removal of prolapsed disc tissue persists because the surgery did not eliminate the loosening of the motor segment, which is an important factor in the production of pain. In the bibliography appended to this chapter the reader will find ample references to this subject. Numerous surgical methods are employed to transform the existing loosening into a permanent rigidity, including complete removal of the disc and spinal fusion, either with a bone graft or with fixation by plastic or metallic screws or nails (p. 157). Several writers have advocated an abdominal approach for this fixation (Hult, Junge, Lane and Moore, Vogel, and others).

Numerous clinical investigations and pathologicoanatomic studies have been carried out in an effort to determine the relationship between disc prolapse and certain syndromes of spinal pain. It is difficult to relate pain to the presence of a Schmorl's node in the spongiosa, and Schmieden, Brandes and W. Muller warn against the explanation of pain syndromes by radiographic findings. However, Dietrich, Gladyrewski, Mooney, Schwede, Teneffe et al. have observed pain on pressure and percussion, and limited spine rigidity caused by pain with arthrosis of the small vertebral joints at the level of vertebral bodies containing Schmorl's nodes (Morasca). Schanz considers Schmorl's node as the anatomic basis for "vertebral insufficiency" (*i. e.*, the inability of the vertebral body to resist the stresses imposed on it), and Kümmell believes it related to the syndrome bearing his name (p. 96). The question of the traumatic origin of Schmorl's nodes is of major clinical interest and will be discussed on page 180 (fig. 340).

There is a rather voluminous literature dealing with the symptomatology, diagnosis and treatment of posterior disc prolapse. Many posterior prolapses, anatomically proven, remain without much clinical significance (posterior Schmorl's nodes). This is particularly true in the case of small prolapses lying in the sagittal plane or near the midline, but a large fragment of disc tissue or one prolapsing in the posterolateral direction, may well produce pressure on the nerve roots. The various aspects of this condition, from simple detachment of a fragment of disc substance to the multiple forms of true prolapse (recurrent, fixed, free, migratory, etc., cf. p. 144 ff.), give rise to numerous transient symptoms and make its clinical and radiologic recognition a difficult problem. Disturbances in the internal structure of the disc and the early stages of prolapse of a detached fragment are among the common causes of so-called "lumbago," a term loosely applied to pain in or near the spine. The anatomic studies of Lindblom and Rexed, and others have demonstrated the overwhelming frequency of posterolateral prolapse, causing nerve root pressure and radiating pain, the distribution of which corresponds to the sensory fibers arising in the affected root. Thus there occurs suboccipital neuralgia, brachalgia, intercostal neuralgia, ischalgia etc. The subjective symptoms plus the neurologic findings of changes in the reflexes, loss of sensation, muscle atrophy and weakness, etc., permit the tentative diagnosis of a root lesion resulting from pressure, even when there are no demonstrable roentgen findings. There are, of course, other causes of root pressure: narrowing of the intervertebral foramina (p. 125), radiculitis, Pott's disease, tumors, vertebral dislocation and osteophytes on the posterolateral vertebral borders. These questions are of great practical importance and have been discussed extensively in the various publications which deal with disc prolapse.

Keegan's schematic presentation of the causes of radicular pain is a very useful one, although it needs a few corrections (Gronemeyer, Reischauer, Taptas and Bayulkem)

The various possible sites of localization of disc prolapse in relation to the nerve roots are shown in figure 284 At the level of the L 4—L 5 disc, a large prolapse may involve two nerve roots, either simultaneously or alternately, producing nerve root disturbances Usually only one root is involved (left, in fig 284) with compression from without, or from within by the angle formed by the dura mater and the root A prolapse occurring more medially may give rise to vague pain and, by compression of the fibers of the cauda equina, may give rise to pain which shifts from one side to the other (cf figs 270 and 271) Additional bibliography Barr, Belart, Copeman and Ackermann, Dubs, Falconer and Cole, Fineschi, Fineschi and Kirchmair, Friedmann, Hadley, Hampton and Robinson, Hohmann, Hult, Jäger and Lehmann-Facius, Kroll and Reuss, Kuhlendahl and Richter, Malmros, Pette, Pia and Haag, Rathke and Heiperts, Römer, Scheller, Schüller, Spurling and Grantham, Star and Fuhrmann, Susse, Tarlow, Voss-schulte and Börger, Weber, Wiberg, Wolman, Woodhall and Hayes, Wycis et al

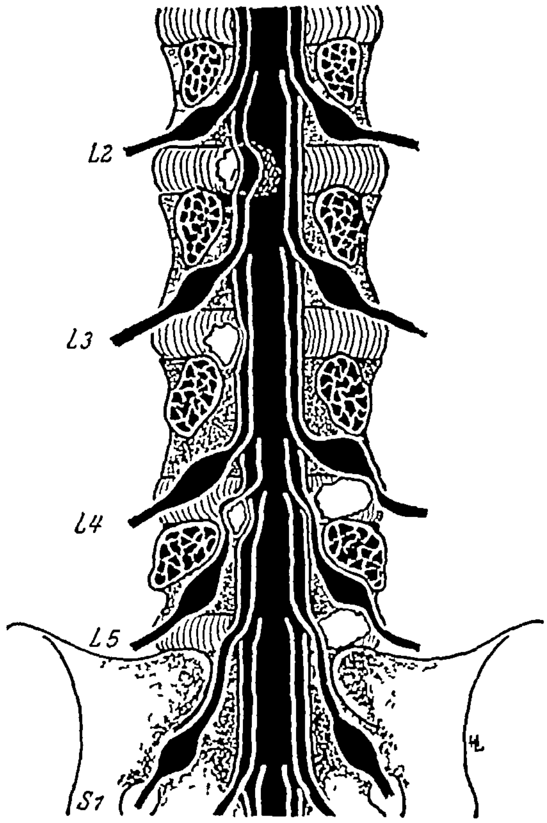


Fig 284 The relation of disc prolapse to the nerve roots Midline prolapse (L 2) provokes a pain syndrome which is not very characteristic, the cauda equina syndrome Unilateral prolapse (L 3, left) may compress the L 4 root from without or it may compress two roots at the same time (L 4, left) The prolapse of large amounts of disc tissue (L 4 and L 5, right) may provoke simultaneous or alternating compression of two roots

It has been generally believed that disc prolapse was essentially a lesion of the lumbar spine, but in recent years the attention of clinicians has been directed to the cervical region where disc prolapse and the resulting pressure on the nerve roots and the vessels may give rise to various disturbances not heretofore understood Such disturbances include angina pectoris, certain forms of hypertension, cervical migraine, shoulder and arm pain and even circulatory disturbances in the brain In these, and in other like clinical manifestations, one must consider not only disc prolapse, but changes in the small joints of Luschka (fig 274), and even osteophyte formation producing pressure on the sympathetic ganglia Thus it would seem that there is needed a rather complete revision of our ideas as to spondylosis deformans and cervical disc prolapse The literature on this subject is extremely voluminous and controversial Baake, Bente with Kretschmer and Schick, Biedermann, Brussatis, Bues, Bucy with Heimburger and Oberhill, Decker and associates, Duus and Kahlau, Duus with Kahlau and Krücke, Exner, Franz, Frykholm, Gayral and Neuwirth, Geissendörfer, Gos and Temple, Grzan, Guillaume and Caron, Gutzeit, Hackethal, Haglund, Janzen, Jefferson, Josey and Murphey, Junghanns, Keegan, Kemmler, Kovacs, Kratochvil, Kristoff and Odom, Krogdahl and Togersen, Kuhlendahl, Kuhlendahl and Felten, Maxen, Metz, Morgenstern, Moritz, Müller, Neuwirth, Parade, Peet and Echols, Pia and Tönnis, Pillokat, Pool, Raney and Hunter, Reischauer, Reuter, Semmes, Sollmann, Spurling and Scoville, Steinert, Süsse and Pfeiffer, Schlegel, Tönnis, Uhlemann, Wanke, Wanke and Bues, W Weber, Zulch, Zukschwerdt and others Certain particular aspects of clinical findings related to the uppermost articulations of the cervical spine are discussed in chapter I H and chapter III G

Posterior prolapse of a disc causes not only disturbance of the motor and sensory nerves, but also affects the autonomic system This is almost certainly the case in some of the disturbances mentioned in the preceding paragraph Involvement of the autonomic system is not only more common in the cervical region but is more easily recognized Its ocurrence in the lumbar area is accepted by some

investigators but disputed by others (Reischauer) We do not know whether the involvement of the autonomic system is direct involvement by the prolapsed disc tissue (see p 22) or a vascular disturbance of reflex origin This problem was studied in detail by Bannwarth, Bäcker, Diener, Dittmar, Jaeger, Pette, Reischauer, Saeker, Schrader and others

Gutzeit, who placed great emphasis on spinal lesions as etiologic factors in various diseases, published a great deal of work on this subject He believed all hyperemic or ischemic pain, some forms of migraine, Sudeck's syndrome and trophic edema to be of vascular origin In Reischauer's book on the cervical syndrome and in Haferkamp's monograph entitled, "Spine changes as etiologic factors in disease processes," the viewpoint of many clinicians is presented as to the relationship of spinal lesions and such varied conditions as eighth nerve disorders (Moritz), heart and circulatory disturbances (Altmann, Killing and Mohing, Parade and Bockel et al) and decreased pressure of the cerebrospinal fluid (Domnick) The significance of the changes in the cervical spine in instances of periarthritis of the shoulder joint, epicondylitis, "Dupuytren" contracture, and tenosynovitis are receiving more attention in the literature (Hagen and Peters, Kaiser, Kuhlmann, Mohing, Mordega, Reischauer, Scholz) Damage to the intervertebral disc of the lumbar region is becoming more important in obstetrics and gynecology (Kirchhoff, Kleine, Martius, Sicard and Sureau, Schwenzer and others), and this is also true as far as the relation of the intervertebral discs to interference with the blood supply of the extremities is concerned (Presch) Electromyographic changes with spinal disorders were also observed (Marguth with Orbach and Vetter) Radicular pain may simulate the acute surgical abdomen and may lead to unnecessary surgery (Epstein)

A comprehensive discussion of the problem of conservative and surgical treatment would go beyond the limits of this volume Only since World War II has the posterior prolapse of the disc been hesitantly approached surgically Successful therapeutic results stimulated much interest and in recent years numerous publications appeared (Coenen, Ellmer, Jaeger, Kortzeboen, Löwenstein, Schachtschneider, Siegmund, Wertemann and Rintelen) Among the many German publications which appeared after 1945 are Bäker, Bannwarth, Beck, Haeussler, Hofmann, Idelberger, Jäger, Junge, Junghanns, Kehrer and Krischek, Köbcke, Kuhlendahl, Kuhlendahl and Hensell, Kreuz, Kroll and Reiss, Laubendahl, Major, Mutschler, Pette, Reischauer, Rössler, Schöler, Schulte, Stimpfl and Zohlen

A thorough investigation of the various methods of conservative therapy has revived the interest in the manipulation technics of the treatment of the various spine disorders These were already practiced by physicians in ancient times (cf chapter VIII), later taken up by lay persons, and gradually used in a distorted form as mystic rites or associated with sectarian practices They found their way, however, into the medical literature and medical practice again, and now are used as manual vertebral spine therapy and various forms of physical therapy These problems were investigated by Bäker, Biedermann, Cramer, Derbolowsky, Dreyer, Gutmann, Gutzeit, Illi, Kayser, Mau, Peper, Rettig, Rohrmann, Schrade and Noeske, Sell, Sollmann, Storck, and Zuckschwerdt, Not only are the manual manipulation methods revived, but others are added and tested, such as corsettes, mobilization apparatus inducing rhythmic extension of the vertebral column, various tables including the table with a Glisson's traction sling, and many others (Ammann, Claussen, Cyriax, Jackson, Judovich and Nobel, Mielke, Neuwirth, Rathke, Shenkin, Sollmann, Ulrich, Weber, Weiss and Brussatis, Wyss and Ulrich et al) About such conservative treatment and methods as massage, physical therapy, immobilization in supportive corsettes of various forms, and injections (paravertebral, peridural, intravenous of Impleton, novocaine, hydrocortisone, and many others) exist numerous publications of which the following are mentioned Armstrong, Blumensaat, Elle, Ewald, Galli and Scharll, Gamp and Gros, Gutzeit, Heiss, Jaeger, Kroll, Lühmann, Rabl, Reischauer, Rothenberg with Mandelsohn and Putnam, Schuknecht

Undoubtedly, there should be more attention paid to the various stresses produced by modern life (Junghanns) and various methods of preventing the resulting syndromes should be devised (Akerblom, Blumensaat) Reading and writing today, is carried out almost entirely in the sitting position at a desk or table with a horizontal surface This requires bending of the head and neck and a shifting of the center of gravity of the head to a point beyond the weight-bearing axis of the

cervical spine. Chairs should be constructed which afford adequate support for the back. That cervical lesions producing the neck-shoulder-arm pain syndrome are of such common occurrence today makes it difficult to ignore the fact that, formerly, nearly all reading and writing were done at a standing desk with an inclined surface. Prolonged typing, with the arms elevated and without adequate back support, must also be considered as an etiologic factor in the production of such a syndrome. Since many people with back pain are more comfortable lying on a firm mattress, and without pillows, perhaps more attention should be given to construction of mattresses.

Although, in selected cases, conservative methods of treatment of disc prolapse have had very satisfactory results, surgical methods are not to be discarded, and at the moment the consensus is that surgical intervention is to be considered after more conservative methods have failed. There is a constantly increasing volume of publications on this subject, and some of them dealing with this particular aspect are: Albrecht, Blumensaat, Brailsford, Decker and Buffat, Duran-Obiols, Ectors, Erlacher, Fineschi, Hattori, Hayashi, Junge and Sievers, Kane and Lane, Kelley with Voris, Svien and Ghormley, Kondo with Yamada and Ito, Kuhlendahl, Kuhlendahl and Hensell, Penholz, Scuderi and Khedroo, Seeley with Hughes and Jahnke, Sicard, Sprung, Svaar, Schlegel, Schönbauer, Schröder, Törma, and Wertheimer.

The various features of posterior disc prolapse and the problems of differential diagnosis which arise need thorough investigation which will be achieved only by close cooperation between the clinician and the pathologist. At the Mayo Clinic, studying 10,000 patients with back pain, Raaf found that only 1.8 per cent had prolapses which justified surgical intervention. Even though this is a very small percentage, many thousands of operations for disc prolapse have been carried out. Originally, rather extensive laminectomies were necessary to gain access to the prolapsed disc tissue. The development of surgical technic now permits a so-called "interlaminar fenestration" of the ligamentum flavum. A thoughtful consideration of spinal function is the essential guide to the therapeutic approach, remembering that disc prolapse is not a simple process localized in the "body disc amphiarthrosis" but is a process involving the entire motor segment (Junghanns). The symptoms are the result of both the prolapse and the "loosening of the motor segment," and both require treatment. If the surgeon simply removes the prolapsed portion of the disc which was producing pressure on a nerve root, then only the symptoms of nerve root pressure have been relieved. The "loosening of the motor segment," with its functional significance, also requires treatment either by prolonged immobilization or by surgical fusion. The latter is highly regarded by such writers as: Arnaud with Rampal and Montagnier, Brussatis and Muller, Catalano, Cauchoix and Lemoine, Cloward, Crawford with Mitchell and Granger, Debeyre with de Sèze and Jurmand, Dodge with Svien and Janes Ingebrigtsen, M. Lange, Reimers, Spadea and Hamlin, Steindler and others. All of these problems have been discussed from such varying viewpoints that the literature is confusing. The clinical and radiologic recognition of disc prolapse, the differential diagnosis, true and false recurrences, multiple prolapses, operative results (some writers report more than 1,000 cases treated surgically), and the cause and the prevention of failure have been dealt with in a rich and prolific literature: Adams and Coonse, Alajouanine, Alajouanine and Thurel, Anderson and Wexberg, Babcin, Barr, Bedrna, Bergmignon and Chaillon, Blum, Bradford and Spurling, Brailsford, Brain, Brocher, Brüssowa and Santockij, Caesar, Cech and Skl, Connel, Coplans, Crisp, Dandy, Debrunner, Decker and Buffat, Delmas-Marsalet, Dickson, Echols, Falconer with McGeorge and Begg, Firica, Friberg, Galland, Grant and Nulsen, Gurdzian and Webster, Harmon, Herbert, Hinrichson, Hirsch, Hutton and Jung, Krayenbühl, Krayenbuhl and Klingler, Krayenbuhl and Weber, Kunz, Lewey, Lièvre, Marble and Bishop, Maurice, Morrier, Morrisey, Nitsche, Nordenfeld, Norlén, Olivecrona, Pampari, Paulian, Peet and Echols, Pennybacker, Petit-Dutaillis and Pertuisset, Peyton and Simmons, Pia, Popowa, Poppen, Raaf and Berglund, Raney, Robertson and Teacher, Roeder, Rövig, Sashin, Schnell, Schröder, Shinners and Hamby, Sicard with Welti and Petit-Dutaillis, Stender, Stirnweiss, Tans, Tavernier, Woodhall and Young.

C. Degenerative lesions

1. Intervertebral chondrosis

The most striking finding in the aging of disc tissue is dehydration, a change most marked in the nucleus pulposus (p 18) Not only is there an increasing loss of resiliency, but the signs of wear and tear begin to manifest themselves The physiologic decrease in water content initiates a series of disc changes, previously discussed, which constitute the syndrome of "intervertebral chondrosis" (chondrosis intervertebralis) The principal causes of disc degeneration, inevitable after a certain age, are dehydration, the functional strains of everyday life, the extra strains produced by abnormal curvatures, increased stresses, etc

Fig 285 Photograph of a horizontal section of a disc The structure of the annulus fibrosus is well preserved The nucleus pulposus and the posterior parts of the annulus fibrosus are discolored (brown degeneration)

It is possible that changes such as these may be the result of hypoxemia (Büchner) which cause damage during the embryologic period, and investigation of this possibility is to be encouraged (chapters I C, II A, II A 8) Fudalla's theory of allergy as a cause of degenerative changes remains to be proven, and Vogler thinks that shrinking of the elastic components of the disc occurs in the presence of arthritic involvement of the disc or the adjacent tissues Moreover, the role of hyaluronidase in the water metabolism of the disc (p 15) needs extensive investigation (Naylor and Smare, Ott)

There is an increasing body of opinion that the damage from long-continued strain plays an important role in the occurrence of the degenerative changes which involve the disc, but additional pathologicoanatomic studies and practical clinical and radiologic observations must be made before we can determine whether the excessive strain is, in itself, the cause of degenerative changes in the disc or only an aggravating factor Certainly, modern methods of transportation give rise to stresses not anticipated in the structure of the spine The problem of "initial trauma" needs additional study (Junghanns, Schlegel, Zohlen) Bibliography Baumann, Exner, Hirsch and Nachemson, Lindemann and Kuhlendahl, de Sèze, and others (cf chapter I C, pp 15, 145, 146, 174)

Disc degeneration manifests itself in multiple forms When a disc of an elderly person is sectioned, it is seen to be dehydrated, and the nucleus pulposus, humid and elastic in youth, has no tendency to protrude itself from the sectioned disc and appears to be dry and friable It may show quite marked changes in its color, sometimes light yellow, sometimes a dark brown This brown degeneration (fig 285) is produced by the deposition of a pigment of unknown origin, but which Schmorl and Güntz have shown to be unrelated to blood pigments In ochronosis extensive pigmentation of the discs may be observed, sometimes with concurrent ossification (Diebold)

With the beginning of dessication there occurs widening of the spaces between the layers of the nucleus pulposus (fig 32), and fissures form, radiating from the region of the nucleus into the annulus fibrosus Radiographs of preparations injected with opaque media show these ramified and extended fissures (figs 286—292), often extending obliquely and transversely beyond the nuclear region into the annulus fibrosus, sometimes even entering the epidural space (fig 292) The relationship of these phenomena to posterior disc prolapse has been discussed in chapter IV B 2, p. 144 ff. The visualization of these changes in the living subject has been mentioned on pages 148 and 149

The central disintegration of the disc structure (figs. 294 and 295) is not necessarily limited to the nucleus pulposus from whence it extends to the annulus fibrosus but may involve only the annulus Where this is true, the areas of degeneration and loosening of the fibers of the annulus show a concentric arrangement and, in a transverse section, are seen to effect semilunar and falciform sections of the annulus There occur, also, crescent-shaped sequestra of the annulus (fig 296).

It is not unusual in the thoracic region (fig 386) of an aged person to find concentric tears in the anterior portion of the annulus fibrosus along the inner margin of the bony rim, and this will be discussed in detail in the chapter on senile kyphosis (chapter VI A 3) We do not know whether these tears are of purely degenerative origin, or whether unusual strain and stress is of importance in their development

According to Übermuth, degenerative changes begin to appear in the cartilaginous plates shortly after the end of the growth period, beginning as small areas of degeneration at the original site of passage of the notochord This is also the site of election for Schmorl's nodes (p 13) Übermuth's thesis that these changes initiate spondylosis deformans is not borne out by later studies and we will discuss this in chapter V The relationship between these areas of degeneration, as described by Übermuth, and the chondrosis desiccans described by Reimers, and their role in disc prolapse (p 145) is not yet clear

Fig 286 Photograph of a sagittal section of a disc Woman of advanced age Note the S-shaped tear running in a horizontal direction through the entire disc with destruction of the fibers of the "rim annulus" (to the right in the figure)

Healing, in the sense of regeneration, is no longer possible once the disc tissue has undergone desiccation, loosening, fissuring and sequestration In general, the changes are progressive and stabilization may be achieved only with the occurrence of sclerosis, discussed in connection with disc prolapse on page 149 (see also chapter IV E)

The fissuring which occurs in intervertebral chondrosis sometimes may be recognized in the radiograph (fig 293), where it appears as linear translucencies in the disc (Höffken, Knutsson, Mardersteig, Raines, Vilasca with Infiesta and Teixidor), but this should not be confused with the extended nuclear cavities seen with osteoporotic biconcave vertebrae (fig 230) For Kröker, this "pneumatization," not observed in traumatic infectious lesions, was pathognomonic of chondrosis, but nothing permits us to affirm this Except for these positive radiologic signs, rarely encountered, there are no radiologic findings which permit the recognition of early manifestations of intervertebral chondrosis Junghann's functional radiography (p 148) may be of use in the recognition of early changes The narrowing of the disc space is slight and the vertebral margins will show radiographic changes only if they participate in the over-all picture of Schmorl's node formation The radiographic findings become

Fig 287 Photograph of the surfaces of degenerated discs with colored gelatine injected before cutting The clefts are not limited to the region of the nucleus, but are also demonstrated in the annulus fibrosus They show a concentric course following the layer structure of the annulus fibrosus The upper disc exhibits a tear running backward from the annulus, passing at right angles through all the layers of the annulus fibrosus The disc tissue has prolapsed into the vertebral canal

increasingly more prominent as intervertebral chondrosis transforms itself into the more advanced stage of osteochondrosis intervertebralis, as is seen in figures 299—301

It is difficult to establish the frequency of occurrence of the various types of disc degeneration which have been discussed and which will be further discussed later With increasing age these lesions become more frequent and more extensive, as can be shown by the statistical tables for

Fig 288 Lateral radiograph of the spine Man, age 74 Radiopaque fluid has been injected into the disc The disc space is narrowed and the clefts are filled by the opaque fluid and ramify through the entire disc space and reach the vertebral canal (chondrosis)

Fig 290 Radiograph and photograph of a part of the lumbar spine Man, age 75 The upper figure shows two lumbar discs filled with radiopaque material The photograph shows a sagittal section through the fourth lumbar disc (the lower one in the radiograph) The comparison between the photograph and the radiograph reveals the similarity of the clefts when filled with opaque fluid and the clefts as seen on a cross section (chondrosis)

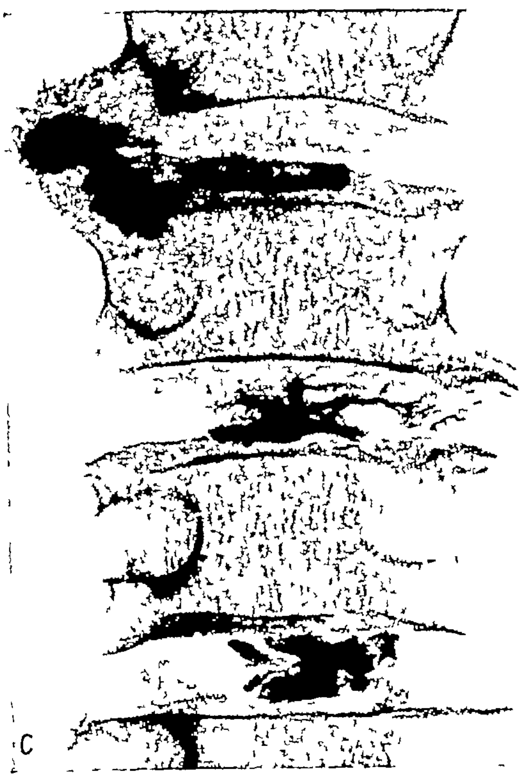


Fig 289 Radiograph of the spine after removal of the vertebral arches Man, age 71 Anteroposterior projection Radiopaque fluid has been injected into the discs In contrast to the injected preparations of normal discs (figs 32—35), extensively ramified clefts are seen throughout the entire disc Clefts filled with injected material also extend to the large marginal overgrowths

spondylosis deformans, a disease in which the degenerative changes in the discs also play an important part (p 186) These changes are both more frequent and more severe in the lumbar region than in other areas of the spine Friberg and Hirsch found definite signs of degenerative disc changes in nearly one-half of the radiographs of living persons examined

Fig 291 Lateral radiograph of a part of the lumbar spine Man, age 56 Radiopaque fluid was injected into the discs by a ventral approach upon autopsy The third lumbar disc (x) exhibits a fairly normal pattern of the nucleus The fourth lumbar disc shows marked cleft formation and posterior prolapse of part of its content into the vertebral canal (arrow) recognizable by the extravasation of the opaque fluid

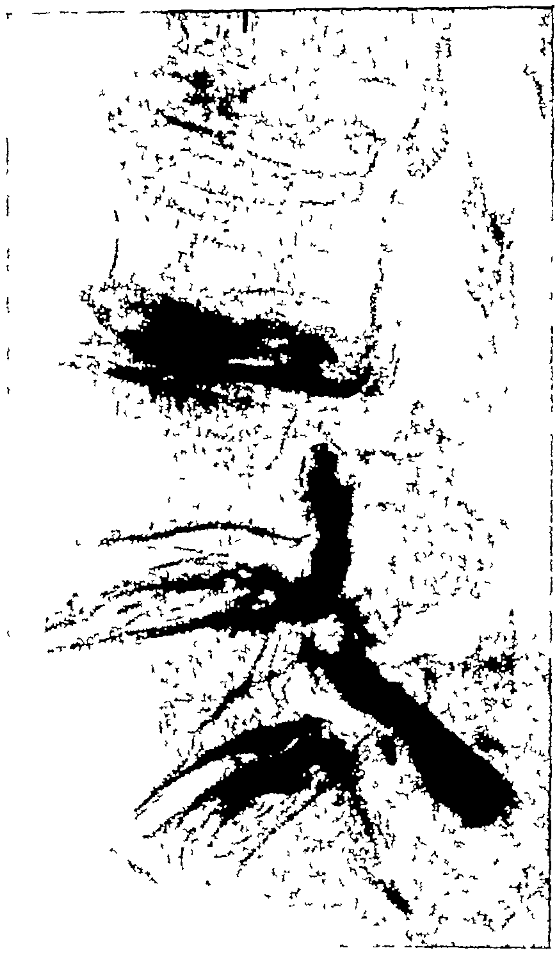
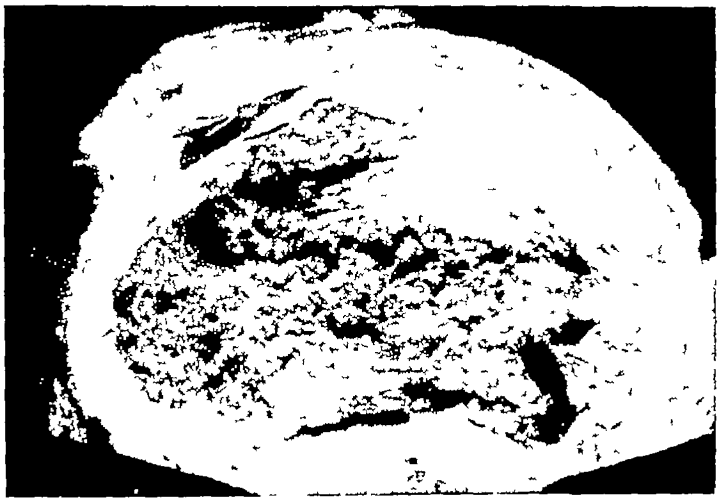


Fig 292 (right) Lateral radiograph of the lumbar spine Man, age 82 Radiopaque fluid was injected into the discs The fluid not only filled the ramified clefts in the much degenerated discs, but it has even extended into the vertebral canal through the clefts, and has spread between the dura mater and the vertebral body

Fig 293 (left) Part of a lateral radiograph of a cervical spine Man, age 32 With the head sharply extended, the intervertebral space between C 6 and C 7 becomes wider anteriorly and a discrete radiolucent band parallels the anterior and inferior border of C 6 With the head in the neutral position this radiolucent area is not present Degenerative osteophyte formation in the vicinity of the damaged disc (C 6—C 7)

Fig 294 (right) Photograph of a section through the fifth lumbar disc of an old man Considerable disintegration of the disc structure is present, especially in the region of the nucleus, and also in the annulus (especially in the left posterior portion in the figure)

The minor changes in the discs, which are the result of ordinary wear and tear, do not occasion definite clinical symptoms and findings Certain vague complaints referred to the back are commonly explained as arthritis or as muscle spasm produced by pain, but these point to disc changes The differential diagnosis is difficult, especially as regards possible early infectious processes Usually, these changes represent "loosening in the motor segment," which has been discussed in the chapter on posterior prolapse of the disc (p 154) The segment of the spine which is located immediately above the affected disc or discs frequently shows a flattening of the curve (chapter VI D)



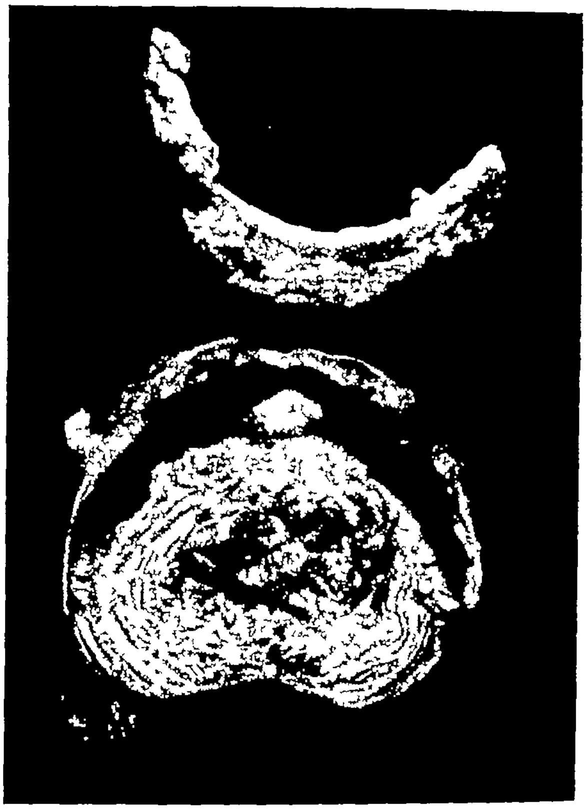


Fig 295 (left) Photograph of the surface of a lumbar disc Disintegration of the disc tissue, especially in the region of the nucleus Chondrosis of the disc

Fig 296 (right) Photograph of the surface of a lumbar disc Chondrosis of the lumbar disc with sequestration of a crescentic disc fragment ("loose articular body")

Fig 297 Microphotograph of the body disc border of an L 5 — S 1 disc Detachment of the disc from the vertebral body The normal cartilaginous plate is missing Irregular cartilage proliferation is seen on the adjacent vertebral body surfaces (osteochondrosis)

If the disc lesions we have just described result from dessication and the aging process in general, we may speak of "primary intervertebral chondrosis," but if the causes lie outside of the intervertebral spaces, then it would seem more appropriate to use the term "secondary intervertebral chondrosis " This form results from the numerous pathologic conditions which impose abnormal functional strains on the affected discs Among these are the congenital defects in the vertebral arches (spondylolysis, chapter II B 2) with the associated "loosening of the motor segment" which

Fig 298 (left) Photograph of a sagittal section of the spine Man, age 72 "Charcot spine" with extreme disintegration of nearly all of the discs, narrowing of the disc spaces and sclerosis of the vertebral bodies involving the lower vertebrae In the upper part of the spine the sclerotic changes are limited to the vertebral plates

Fig 299 (right) Anteroposterior view of the spine after removal of the vertebral arches Man, age 72 "Charcot spine" with extreme narrowing of all disc spaces and with sclerosis of the vertebral plates and with osteophyte formation

finally destroys the resistance of the disc tissue by the continuous functional strains and shearing stresses When lesions of the vertebral bodies permit the prolapse of healthy disc tissue (Schmorl's nodes, p 138), secondary intervertebral chondrosis will inevitably appear and both primary and secondary intervertebral chondrosis may progress to their more severe sequel of intervertebral osteochondrosis, to be discussed in a subsequent section That intervertebral chondrosis may be the lesion which precedes the "expulsion of a disc sequestrum," i e , posterior disc prolapse, can be understood from our description of this disease process (chapter IV B 2)

2. Intervertebral osteochondrosis

Primary intervertebral osteochondrosis is to be regarded as the aging process and dehydration, and the various forms of secondary intervertebral chondrosis may assume, frequently, a serious character The internal derangement of the disc tissue may go so far as to produce extensive disintegration and an accompanying decrease in the disc space (p 131), sometimes associated with the

formation of a large cavity within the disc The outermost layers of the annulus fibrosus are usually well preserved, and on inspection of a spine removed at autopsy they protrude beyond the outer surfaces of the vertebral bodies (Hildebrandt) The cavity just referred to is dry, brittle, greyish-white tissue attached to the superior and inferior surfaces of the adjacent vertebrae, representing the residue of disc tissue which has been pulverized by spinal movement (figs 294 and 295) In the living this may be visualized, rarely, as a pale area in the disc space (Mardersteig, Raines) Fragments

Fig 300 (left) Lateral radiograph of the specimen seen in figure 299 Considerable thinning of the discs, sclerosis of the adjacent spongiosa and with osteophytes involving even the small vertebral joints

Fig 301 (right) Lateral radiograph of a sagittal section of the lumbar spine Elderly man Considerable narrowing of the disc space with marked sclerosis of the adjacent bones and with osteophyte formation on the vertebral bodies There are also a few osteophytes on the posterior edge of the bodies, and there is some narrowing of the intervertebral foramina

of dessicated disc of falciform or irregular shape may appear as "loose bodies" in the cavity produced by the process of disintegration (fig 296) The adjacent cartilaginous plates may show extensive degenerative changes, or in severe cases may be absent completely There may be numerous small foci of cartilaginous proliferation ("arthritic cartilaginous nodes", fig 297) on the opposing surfaces of the vertebral bodies with marked sclerosis of the trabecular bony network (fig 298) The vertical diameter of the intervertebral space is always decreased in these cases, and an exact description of the gross and microscopic changes may be found in Hildebrandt's paper The decreased height of the disc space and the condensation of the bony trabeculae is clearly demonstrable radiographically (figs 299—301) These changes were called "osteochondrosis" by Schmorl

Hildebrandt, studying Schmorl's serial sections, found that intervertebral osteochondrosis may involve any or all of the discs Sometimes, only a few discs are affected, but frequently all discs, especially those of the lumbar region, may undergo these changes (fig 300) In order of frequency, the lower lumbar discs are the most frequently involved, with the lower cervical discs next in order Males are affected more frequently than females and it seems probable that the functional strains of weight-bearing and mobility account for the more frequent occurrence of osteochondrosis in the lower lumbar and cervical regions In chapter IV F 3 the occurrence of this syndrome as a sequel to traumatic disc lesions is discussed The trauma of manual labor probably has some etiologic relationship to these conditions Constitutional factors are of great significance The relationship of exhausting

disease states is not clear Well-preserved discs are sometimes found in manual laborers of advanced age, while extensive degenerative changes have been observed in persons who have never engaged in manual labor or in strenuous sports Erdman found that intervertebral osteochondrosis is twice as common in persons with a transitional type of vertebra in the lumbosacral region as in those without anomalies (chapter II C 4 a) The most severe forms of this disease, with associated sclerosis of the adjacent vertebral bodies, is found in cases of tabes dorsalis (Alajouanine and Thurel, Bocci, Gold, Hoffman, Lachs, Lyon, Markov, Pape, Sinakovic), and Bocci thinks that this "vertebral osteoarthropathy" may be an early sign of tabes Because of the absence of pain, abnormal movements between the vertebral bodies may become so great as to produce sclerosis involving them as a whole (figs 298—300) Ehrlich found comparable findings in ochronotic alkaptonuria

Exacerbation of a secondary intervertebral chondrosis is possible, resulting in a severe intervertebral osteochondrosis, especially, in spondylolisthesis and other forms of "gliding or slipping vertebrae" (chapter II B 2 and chapter VIII), since a displacement between two vertebral bodies is associated with destruction of disc tissue, the degenerative changes are a natural sequel The disease picture thus produced is of considerable significance in many lesions of the spine The term "lumbosacral arthrosis" is frequently employed, especially if the last presacral disc is involved (Barsony, Kienböck, Sashin, Saxl and others)

"Healing" of the damaged disc tissue is a possibility, both in the milder forms of intervertebral osteochondrosis and the more severe disturbances and commonly results from the infiltration into the damaged zone by vascular and connective tissue (p 158) Usually, this results in loss of mobility of the two adjacent vertebrae and is accompanied by rigidity of the involved area (Hildebrandt, Schmorl, cf chapter IV D)

Intervertebral osteochondrosis, the most serious internal derangement of disc structure, exhibits both marked clinical manifestations and typical radiologic findings (figs 299 n 301) The damage to the nucleus pulposus, the structure of the annulus fibrosus and the cartilaginous plates produces, inevitably, abnormal mobility of the two involved vertebral bodies and, thus, a "loosening of the motor segment " Pain on motion, muscle spasm produced by pain, and abnormal flattening of the spinal curves are among features which are regular sequelae of the events described Moreover, the narrowing of the disc space may decrease the caliber of the intervertebral foramen with the resulting symptoms of root pressure (cf disc prolapse, chapter IV B 2, p 148, chapter III N) Additional bibliography Jud, Lindemann and Kuhlendahl, Pfleiderer, Teneff, Williams and others

3. Calcification

In 1858 Luschka described chalk-like material imbedded in the nucleus pulposus, and in 1897 Beneke observed vaguely outlined dark areas in the disc which he believed to be due to increased calcium content Not until 1922 was calcification in the intervertebral disc demonstrated radiographically in a living person (Calvé and Galland) Schmorl carried out the first anatomic studies of calcification and found deposits of calcium salts in the discs (fig 302) In a few cases of gout, he found deposits of urate crystals He classified the calcium deposits (especially those occurring in the region of the nucleus) as primary (degenerative change) and secondary (infections), and considered that it was quite possible that trauma might be a factor in the production of the calcification associated with degenerative changes

Subsequently, clinicians and radiologists became interested in the problem of disc calcification Some regarded trauma as a principal etiologic factor in the occurrence of disc calcification (Barsony and Polgar, Galli, Lyon, Rose and Mentzingen, Schapira et al) While others regarded disc calcification as a purely degenerative process, possibly resulting from long-continued stresses, and perhaps as a part of the process of rheumatoid spondylarthritis (Horenstein, Israelski and Pollak, Kohlmann, Kronenberger, Norlen, Parlavecchio, Priessnitz, chapter VII B 2) Still others think that certain inflammatory processes are responsible, and find disc calcification associated with pain on percussion with redness and swelling over the spinous processes and with limitation of motion and similar symptoms (Barsony and Polgar, de Bernardi, Lucca, Lyon and Vogler) Fiedler considers calcification

of the discs following a generalized infectious process as a clinical entity After reviewing the literature, Held divided disc calcifications into a chronic degenerative type and an inflammatory form The chronic degenerative type is the one most frequently seen, occurring largely in elderly patients,

Fig 302 (left) Photograph Horizontal section of a thoracic disc Calcification of the nucleus pulposus

Fig 303 (right) Lateral radiograph Extensive calcification in the region of the nucleus with extension of the calcification anteriorly (L 3 — L 4 disc)

and is most common in the midthoracic and upper lumbar spine The arthritic type is less common, occurs in younger patients and is frequently found in the upper spinal regions (Marx, Schorr and Adler, Silverman and others) That it is a reversible process is shown by radiographic evidence (Baron, Klar, Kohlmann, Lyon) Other considerations suggest that calcification may follow hemorrhage into a disc (Rose and Mentzingen) and Kriegk has described calcification of the nucleus pulposus occurring with herpes zoster

Calcium deposits are found not only in the nucleus pulposus, but even more frequently, they are seen as small calcified areas in the annulus fibrosus In Schmorl's Institute Rathcke made a systematic study of the enormous material available and gave especial attention to horizontal disc sections He found calcification in the annulus fibrosus in 71 per cent of all spines, but only 6 5 per cent showed calcium deposits in the nucleus pulposus The occurrence of calcification in both regions increases steadily with advancing age, and examination of the spines from an age group of 30 to 59 showed 4 1 per cent to exhibit calcification in the nucleus, but in the older age group they were more than twice as frequent (8 7 per cent) Several irregularly placed calcium deposits are sometimes found in a single disc (fig 310)

In sagittal and in horizontal sections of a disc, the calcifications of the nucleus pulposus appear as material occupying the interstices of the nuclear cavity (fig 302) Radiographs of these cases (figs 303 — 306) show findings almost identical with those produced by the injection of opaque media into the nuclear space (figs 32 — 35) The calcium is deposited in the villi and in the little islets of the nuclear space Calcification of the annulus fibrosus, best studied in a horizontal section, may be scattered irregularly over the entire fibrous ring (fig 310) Usually, it occupies the site of small fissures or necrotic zones in the annulus but may involve the entire disc (figs 308 and 309) The relationship of calcification to infiltration of the disc by vascular tissue, and that of hemorrhage into the nuclear space and calcification, is not well understood The

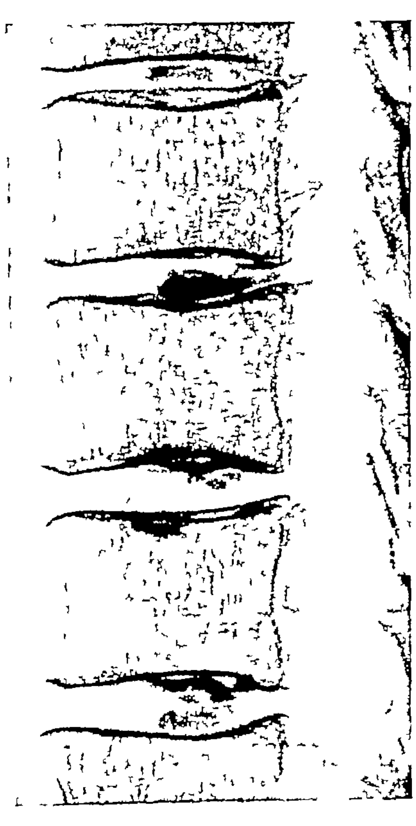


Fig 304 Lateral radiograph of a sagittal section of the thoracic spine Woman, age 58 Foci of calcification in the nuclei of four superimposed discs

question of the relation of disc calcification to back pain has been much discussed in the clinical literature, but no conclusive answer has been found (Annovazi, Arlaborse, Foa, Gendreau with Intras and Dufresne, Guiliani, Guichard and Simon, Morel and Roederer, Ostapowicz, Petit-Dutaillis, Rietema and Kejser, Zeitlin, Zuppa and others



Fig 305 (left) Anteroposterior radiograph of the thoracic spine after ablation of the vertebral arches Woman, age 52 Calcification in the nucleus of the T 10—T 11 thoracic disc

Fig 306 (center) Lateral radiograph of the disc seen in figure 305

Fig 307 (right) Lateral radiograph of the T 8—T 9 disc Woman, age 86 Calcification of the disc extending considerably beyond the nucleus


Fig 308 (left) Lateral radiograph of the lumbar spine Woman, age 75 Irregular, cloudy opacities of varying sizes (calcifications) in the three lower lumbar discs seen in the nucleus and in the annulus fibrosus A small calcified posterosuperior disc prolapse is seen at L 4 — L 5

Fig 309 (right) Lateral radiograph of a sagittal section of the lumbar spine Woman, age 78 Opacities (calcifications) in all parts of the discs A small calcified disc fragment has prolapsed posteriorly (L 4 — L 5) into the vertebral canal Marked osteoporosis

D. Transformation of the discs by various tissues

1. Fibrosis

Focal deposits of fibrous tissue have been observed frequently in the intervertebral discs, in the region of the nucleus, and these were first described by Schmorl They are seen best surfaces of sections in the horizontal plane (fig 311), where they appear as white, shining

Fig 310 (left) Radiograph of a horizontal section of a disc with some adjacent bones Man, age 82 Nu opacities represent foci of calcification in various parts of the disc

Fig 311 (right) Photograph Horizontal section of a disc The nucleus shows dense fibrous degenerative c

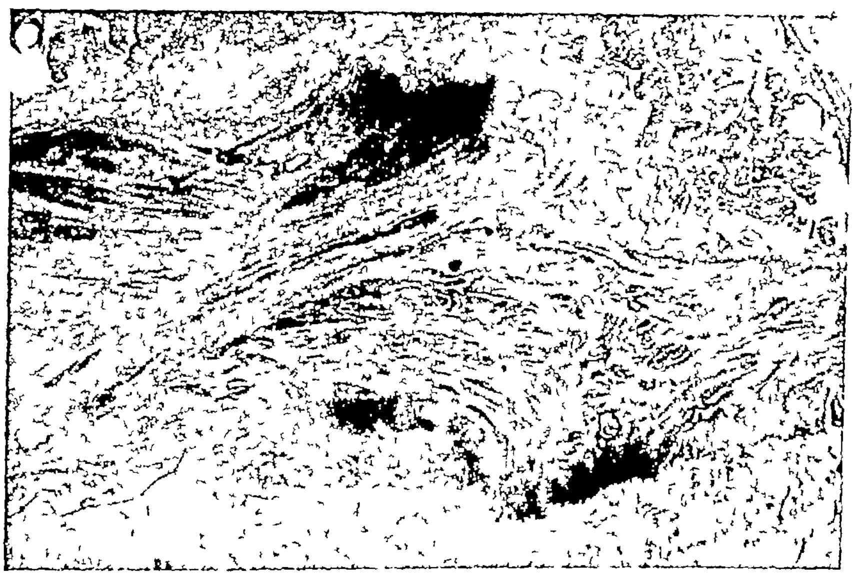


Fig 312 Microphotograph of a sagittal section of a disc Vascularization and fibrosis of the disc and cartila plates Only a small fragment of the cartilaginous plate is preserved (upper left)

dense tissue in strong contrast to the disc structure *This fibrous tissue is markedly lacking in el*ity On microscopic inspection of sagittal sections (and sometimes grossly) one may see that fil tissue from the spongiosa of the vertebral body has passed through fissures in the cartilaginous and into the disc tissue (fig 316), sometimes preceded by a Schmorl's node (fig 315) It is concei that various discrete disc lesions (loosening or small necrotic foci) pave the way for these events it appears that the fibrous changes are always preceded by the appearance of vascular tissue It happen that, except for a small peripheral zone, the entire disc is replaced by connective t (fig 312), resulting in marked narrowing of the intervertebral space Even in the presence of exter fibrous change in the entire disc, the cartilaginous plates may be well preserved The fibrous ti having little or no elasticity, serves to bring the adjacent vertebral bodies together tightly a resulting marked loss of mobility If limited to one disc space, this change is of minor signific as to spinal function and mobility, but its appearance in numerous discs may result in ma

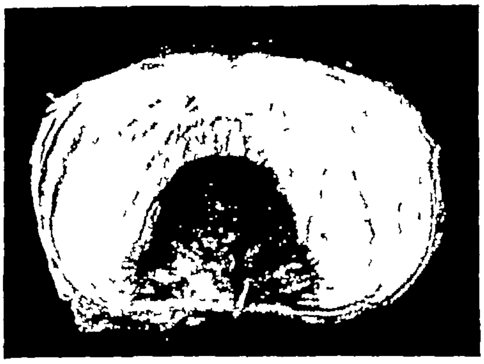


Fig 313 Photograph of a horizontal section of a disc Replacement of the nucleus by vascular and fibrous tissue Sharply delineated dark area represents vessels in a fresh specimen

Fig 314 (right) Photograph of two horizontal sections of lumbar discs Woman, age 72 Fissuring of annulus fibrosus The sharply delineated outlines (which are thin and dark) are healing concentric tears filled by vascular and cellular tissue ("Garland" vascularization of the annulus fibrosus)

limitation of motion (Guntz, Schmorl) The extension of connective tissue into a disc is most common when there are degenerative changes present (chondrosis), the connective tissue serving to fill the fissures and areas of disintegration (pp 159, 165) The narrowed disc spaces are demonstrable in the radiograph (cf pp 160, 165)

2. Vascularization

Aside from the few vessels which penetrate the disc with the extension of fibrous tissue, quite extensive vascular proliferation is sometimes seen in certain discs (figs 313 and 314) The vessels may enter the discs, as does the fibrous tissue, through fissures in the cartilaginous plates, usually in association with an invasion of loose connective tissue (fig 315) On section, the vascular structures are seen to be sharply demarcated from the disc substance and the normal stratification of the disc tissue is no longer demonstrable Focal vascularizations are

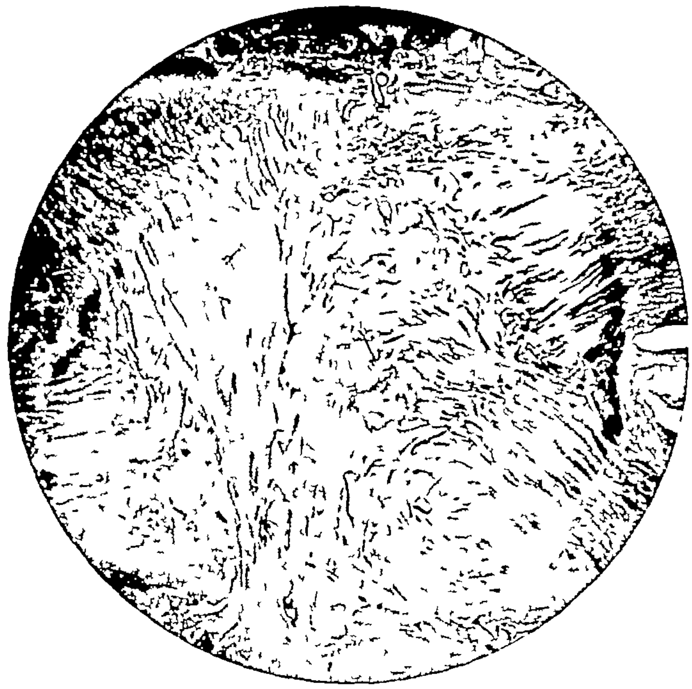


Fig 315 (center) Microphotograph of a sagittal section of the nucleus The nucleus pulposus has been replaced by abundant vascular and loose connective tissue The vascular tissues have come from a cartilage node beneath The bone marrow vessels from above also participate

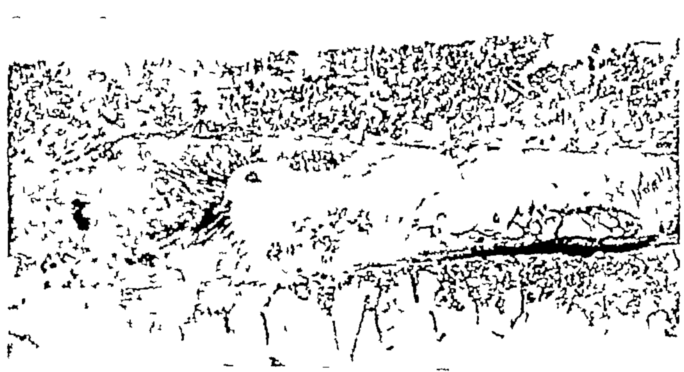
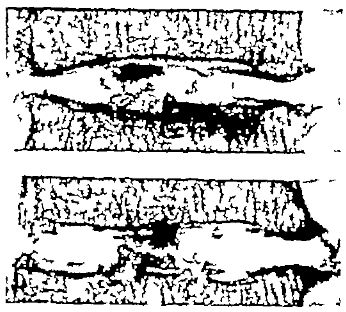


Fig 316 (lower) Photograph of a sagittal section of a thoracic disc Man, middle age The disc structure, particularly in the region of the nucleus, has been replaced by fibrous tissue of fine structure containing numerous blood vessels (vascularization) The penetration of the infiltrating vessels can be seen above and below

more common in the nucleus area than in the annulus fibrosus, where they resemble (fig 314) and represent the scars of concentric fissures in the annulus Radiographica vascularizations are not demonstrable



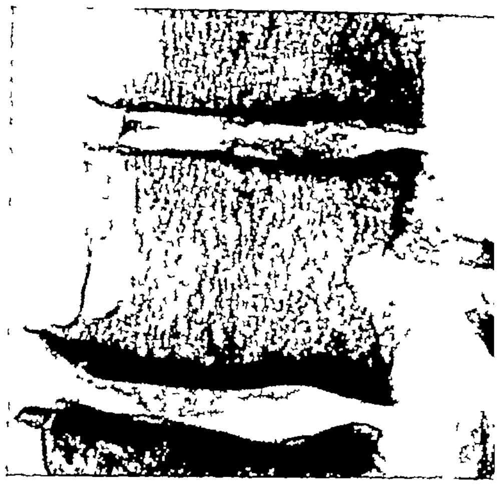


Fig 317 (left) Lateral radiographs of thin sections (sagittal plane) of the spine Man, age 64 Proliferation bone extending into the discs

Fig 318 (right) Lateral radiograph of a sagittal section of a spine Man, age 66 Intervertebral bone pro of vertebral body origin, is seen in the upper disc space Similar proliferations appear in the lower disc seem to project into the disc space from above The shadows in the lower disc space represent lateral overgrowths on the vertebral body above (cf fig 323)

Fig 319 (left) Lateral radiograph of the spine Man, age 70 Osseous inclusion in the annulus fibrosus of the disc near the anterior margin of the disc space Anterior marginal overgrowths have developed on the low of the third lumbar vertebra

Fig 320 (right) Anteroposterior radiograph of the specimen seen in figure 319 (after ablation of the arches) The small oval osseous inclusion in the annulus fibrosus near the anterior margin of the fourtl body is marked by arrows

3. Ossification

The invasion of the discs by vascular and connective tissue is not infrequently accompa bone formation, probably because bone-forming cells have accompanied the invading tissues (f and 318) Large foci of this sort, with their distinct trabecular patterns, are not difficult to d tiate radiographically from areas of calcium deposition Without radiographs in several however, their differentiation from the overgrowths of spondylosis deformans may presen difficulty (fig 318 – 320)

In the formation of "block vertebrae" the discs may be replaced completely by bone, as pro described, while in congenital vertebral synostoses a small residue of disc tissue may pers be recognizable radiographically (fig 46) In general, it is the annulus fibrosus which is repla spongiosa, while remnants of nuclear tissue occupy the center of the disc space

Ossification of the anterior portion of the annulus, firmly uniting the two juxtaposed vertebral bodies, has been previously discussed while describing traumatic lesions of the vertebral rim (figs 179—183), and such processes will be considered in some detail in the section on senile kyphosis (pp 206, 207)

Bone formations, varying in size, may appear in the disc space during or after the healing process following disc damage by trauma (fig 335) or inflammatory disease In these cases sections will show inclusions of fibrocartilaginous tissue in irregular arrangement The "healing" of intervertebral chondrosis by bone formation has been described previously (pp 159, 165)

Fig 321 (left) Photograph Two halves of a disc sectioned in the horizontal plane Woman, age 74 Several layers of the annulus fibrosus have been destroyed anteriorly and small osseous inclusions are seen in these areas

Fig 322 (right) Lateral radiograph of a sagittal section of a segment of the lumbar spine Woman, age 86 Two small osseous inclusions in the L 3 — L 4 disc, near the anterior margins of the vertebral bodies The upper inclusion has united with the rim, while the lower one is free

We must discuss in some detail those deposits of bone localized in the anterior portion of the annulus fibrosus because of the frequency of their occurrence and the difficulties of differential diagnosis which they may occasion The annulus, which is firmly attached to the vertebral rim may show, even in quite young subjects, fissures, small areas of calcification and even deposits of spongy bone Figure 321 shows such bone deposits in two locations on the anterior edge of the annulus The parallel fibers of the annulus are interrupted, and if the bone deposits are quite large, they assume a crescent shape at the periphery of the annulus They may be found, also, in the lateral and posterior portions of the annulus, but they are less common in these regions These deposits of bone, fibrous elements and granulation tissue must be regarded as part of the process of healing of the radial and concentric fissures which appear in the discs

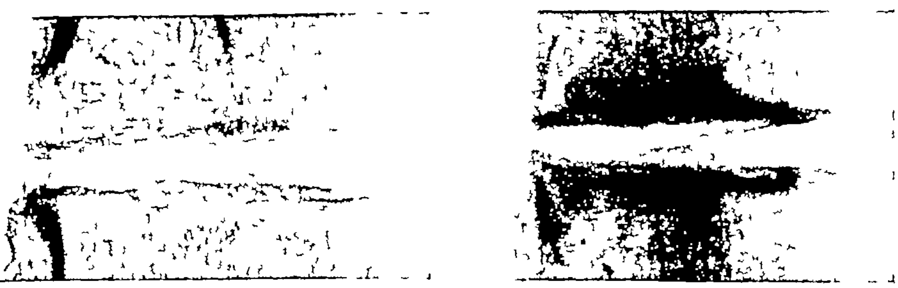


Fig 323 (left) Lateral radiograph of a T 11 — T 12 disc Man, age 25 Bone proliferation of spongiosa origin projects upward into the disc space

Fig 323 (right) The same disc as in figure 323 (left) after ablation of vertebral arches Anteroposterior projection Bone proliferation (as seen in the fig on the left) is located in the nucleus region A comparison with the lateral projection is a safeguard against mistaking this for a marginal overgrowth or a bone embedding in the fibrous annulus (cf fig 318)

In a lateral radiograph these crescent-shaped deposits of bone are seen as small triangular areas near the margin of a vertebra and separated from it by a fine, sharply-defined cleft (fig 324),

Fig 324 Lateral radiograph of the spine Man, age 52 Semilunar bone deposit in the annulus fibrosus of the L 5 — S 1 disc seen near the anterior edge of the fifth lumbar body as a triangular shadow Very slight rounding of the anteroinferior margin of the fifth lumbar vertebra

and such a small deposit of spongy bone with some marginal overgrowth can be seen in figures 319 and 320 The bone fragment which, in the lateral radiograph seems to be very small, is seen in the antero posterior projection (after removal of the vertebral arches) as a fairly large ovoid formation having no connection with the marginal overgrowths Such small bone fragments may appear on the margins of two neighboring vertebral bodies (fig 322) They lie, commonly, very near to the vertebral margin, and sometimes bony union with the vertebral body is clearly seen (fig 322, upper bone fragment) Figure 319 shows their appearance and also demonstrates the osteophyte formation of spondylosis deformans To differentiate between these bone deposits and bony excresences arising from the surfaces of the vertebral bodies, radiographs in two planes must be made (fig 323)

These small bone deposits in the fibrous ring and their relationship to the vertebral rims deserve special attention The descriptive matter and the illustrative figures already presented make it clear that the small bony deposits occur in the outer layers of the annulus, i e , between the vertebral rims of two juxtaposed vertebral bodies When, by a process of maceration, we were able to loosen the bone fragments from the discs, the exposed vertebral body surfaces exhibited rims of normal width and height and normal development, thus demonstrating that no disturbance of ossification in the region of the vertebral rim had occurred In some instances the rim beneath the bone fragment showed slight flattening (fig 324) and a little roughness but nevertheless existed as a closed ring Thus, it does not seem that any disturbance of ossification had resulted in detachment of the bone fragment from the rim, and we are inclined to believe that the flattening and roughness is produced by the mechanical stimulus of motion of the embedded bone fragment against the vertebral rim beneath Although the occurrence of rounded vertebral body margins subadjacent to these small bone deposits led Janker to conclude that the deposits represent rim detachment following a disturbance in ossification, our investigations do not support this theory Rather, we believe that the rounding of the anterior vertebral margin is produced by the friction of the bone fragment against the rim

We do not know the role played by trauma in the formation of small bone deposits in the annulus fibrosus They appear in small areas of necrosis and in fissures in the annulus, both probably resulting from degenerative changes Healing of these occurs by invasion of vascular and connective tissue and, finally, by the formation of bone (cf chapter IV C 1, pp 159, 165)

E. Traumatic lesions

1. Disc injuries without vertebral fracture

Lesions of a disc may follow trauma without injury to either of the two juxtaposed vertebral bodies ("isolated disc injury"), and this has been demonstrated frequently in our serial pathologico-anatomic examinations When vertebral body fractures or dislocations occur, disc lesions are seen frequently at some distance from the fractured vertebral body while the adjacent disc may or may not be affected as described

Table 8

Various Forms of Disc Injuries

1 Injury of the disc only (isolated disc injury)
   a) Injury of a single disc
   b) Injury of several discs
   c) Injury of several nonadjacent discs
2 Disc injuries associated with vertebral body fractures
   a) Injury of the disc in the region of the fracture
   b) Injury of discs remote from the fracture (all forms 1 a—c are possible)
   c) Injury of discs near to the discs and remote from the fracture
3 Disc injuries associated with dislocations
4 Disc injuries associated with fractures of the vertebral arches

The anatomic aspect of a traumatic disc lesion varies greatly and we must differentiate between trauma and intervertebral chondrosis (p 183) It is possible that a pre-existing degenerative change

was an etiologic factor (fig 327), and we are in great need of serial histologic studies which, thus far, are completely lacking Isolated fissures, passing transversely through the layers of an otherwise well-preserved and non-dessicated disc make one suspicious of their traumatic origin (fig 325) Schmorl believes that trauma is a factor in the production of fissures extending posteriorly and related to the development of "posterior Schmorl's nodes" These were described by Luschka as the "posterior recess" of the nuclear cavity (p 141) Severe contusion with extensive stellate lacerations of the disc and the adjacent subchondral vertebral plates (fig 326) is rare, but is always associated with vertebral lesions

Employing numerous spines obtained at autopsy, Göcke studied the response of the discs to pressure, direct violence, traction and hyperflexion and, in so doing, produced findings which correspond to lesions occurring during life As Hirsch and Nachemson have demonstrated experimentally, excessive violence is not necessary to produce disc damage which can follow small, successive and rapidly repeated stresses (p 16) Their work has established the possibility of "fatigue damage" of the disc (p 158), and of the so-called "initial trauma" (Junghanns), which initiates the steadily increasing "chronic" damage to the disc The whole question should have further investigation

Although the recognition of a recent disc injury and its differentiation from the fissuring of chronic degenerative change is difficult, even in the study of the anatomic preparation of the spine, it is very much more difficult to establish a clinical diagnosis of a new, isolated, disc lesion Since the radiograph only rarely exhibits any changes of diagnostic significance, clinical diagnosis is limited to quite rare cases Small fresh fissures give rise to absolutely no radiographic findings, and it requires a rather extensive trauma with prolapse of disc tissue to produce narrowing of the disc space It is not possible to make a definite diagnosis of a traumatic disc lesion by a single radiographic study carried out shortly after the trauma On the contrary, it is only by subsequent radiographic examinations, made at regular intervals, that one may hope to deduce the traumatic origin of the disc changes which have resulted in disc space narrowing These changes will be discussed on page 203 In the presence of symptoms and findings referable to the cord or the nerve roots, and with no evidence of fracture or dislocation, or posterior sequestration of small bone fragments, one may

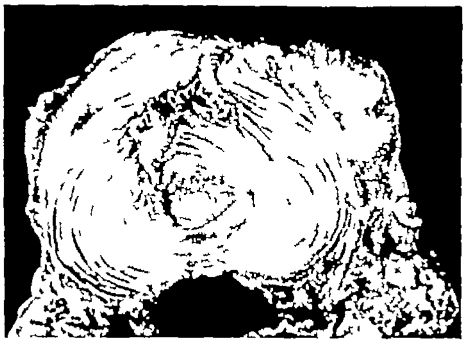


Fig 325

Fig 326

Fig 327

Fig 325 Photograph of a horizontal section of a disc Radial tear of traumatic origin in the anterior part of the annulus, extending to the region of the nucleus

Fig 326 Photograph of a cartilaginous plate after removal of the disc tissue The cartilaginous plate shows a transverse tear with some small collateral tears (traumatic stellate laceration of the cartilaginous plate)

Fig 327 Photograph of the sagittal section of the thoracic spine Man, age 50 Rupture of the anterior portion of the disc following severe trauma From the condensation of the spongiosa it appears that an earlier lesion of the disc had existed Moreover, the anterior portions of the disc above are disintegrated and minor condensation of the spongiosa is noted

suspect a traumatic disc lesion of some severity In such cases one is justified in assuming a recent traumatic posterior prolapse of the disc (cf Chapter IV B 2, p 146)

Schmorl's collection contains discs with recent hemorrhage into the nuclear cavity These are rare and appear to represent the traumatic rupture of abnormal vascular tissue (p 169)

It is unfortunate that there are no figures available as to the frequency of isolated traumatic disc lesions or the involvement of disc tissue in fractures and dislocations of the vertebral bodies and arches Since most spinal injuries do not result in death, the serial examination of autopsy specimens usually discloses only the late sequelae of trauma, obscured by degenerative changes and the aging process Since clinical diagnosis is only occasionally possible, as previously mentioned, there are no clinical statistics of any value Basing our statement on our own experience, we can say that there is no doubt that traumatic disc lesions are much more frequent than clinical diagnosis would indicate, or than is generally believed Therefore, in medicolegal problems involving the relationship of trauma to disc lesions, one must remember that the sequelae, rather than any immediate findings, will permit a diagnosis of disc injury A detailed discussion and an extensive bibliography will be found in the "Handbuch der Gesamten Unfallheilkunde" (Junghanns, 1955, Vol II p 520ff)

2. The changes in intervertebral discs associated with vertebral fractures and dislocations

P.172

In Table 8 we have shown that traumatic disc lesions may occur at some distance from a vertebral fracture, but injury to the disc adjacent to the fractured vertebra is of much more frequent occurrence Although rather mild forms of compression fracture may occur without involvement of the adjacent discs, they are injured in all severe forms of vertebral fractures Rupture of the cartilaginous plates with protrusion of disc tissue into the vertebral bodies may occur (fig 328) and, in severely comminuted fractures, disc tissue from the superadjacent and subadjacent discs may meet in the center of the vertebral body (figs 326 — 331) In fracture-dislocations the anterior portion of the disc and the corresponding portion of the cartilaginous plate may be detached and displaced forward ("shearing fracture") Careful observation of the width and the contour of the disc space, as seen in the radiograph, will permit the recognition of these major traumatic disc lesions Every instance of narrowing of the disc space or disturbance of its outline should make one suspect a lesion of the disc tissue (figs 332 and 333) Infraction of the vertebral plates and their depression into the vertebral body is a definite sign of involvement of the disc (fig 334) The radiographic findings resemble those produced by the sagging vertebral plates of biconcave vertebrae seen in osteoporosis These are serious lesions of the discs, accompanied by rupture of the cartilaginous plates and hemorrhage into the fissured disc tissue, and a comprehension of these changes is essential for the understanding of the late changes which follow disc lesions and which affect not only the shape of the spine, but its mobility and its function

In the clinical and radiologic consideration of vertebral body fractures, it must be remembered that serious disc lesions may be present without alteration of the width or contour of the disc space Frequently, the involvement of the disc can be recognized only by the sequelae which follow, as we shall explain presently, but there are forms of vertebral fractures in which one may be sure of disc involvement, even in the absence of findings in radiographs made immediately after the trauma This is true, for example, in fracture of the vertebral body margin, which is accompanied, invariably, by rupture of the cartilaginous plate and the occurrence of a fissure, running obliquely, in the annulus fibrosus (cf chapter III G 5) In the growth period, the rare comminuted fracture of the bony rim, not yet united to the vertebral body, is accompanied by fissuring and crushing of the annulus, as shown by the narrowing of the anterior portion of the disc space and the later appearance of irregular bone deposits in this area, invariably appearing as a late sequel (cf chapter III G 5)

Disc involvement almost always occurs with fractures of the vertebral arches, since the annulus does not have sufficient elasticity to withstand the forces which produce the fracture Injuries of the ligamentous apparatus must be considered, also, in this connection As is frequently the case, the disc injury associated with vertebral arch fractures will not be immediately apparent but will be recognized by the appearance of the late sequelae We are in great need of pathologicoanatomic

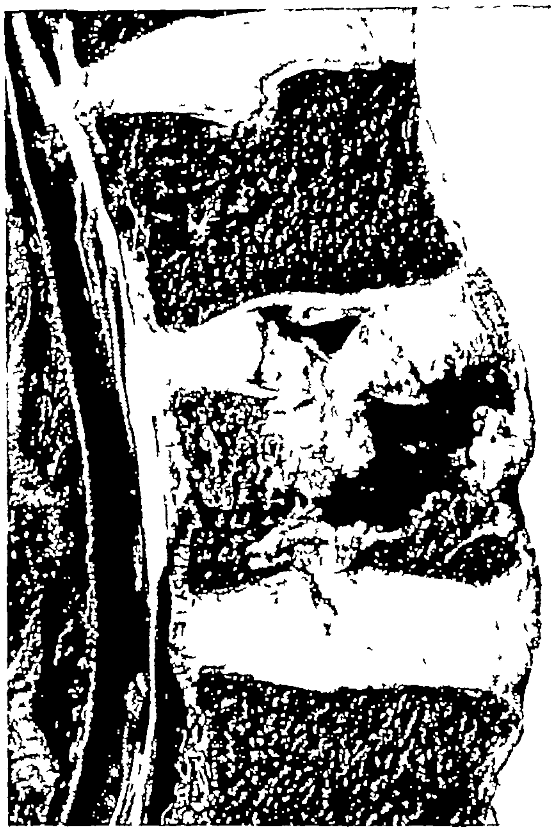


Fig 328 (left) Photograph of a sagittal section of the lumbar spine Compression fracture with hemorrhage into the vertebral bodies Disc tissue has prolapsed into both vertebral bodies (traumatic prolapse of disc tissue)

Fig 329 (right) Photograph of a sagittal section of a lumbar disc Man, age 25 Comminuted fracture of a vertebral body with prolapses of disc tissue from the two adjacent discs A small Schmorl's node with bone envelope is seen on the upper vertebral body

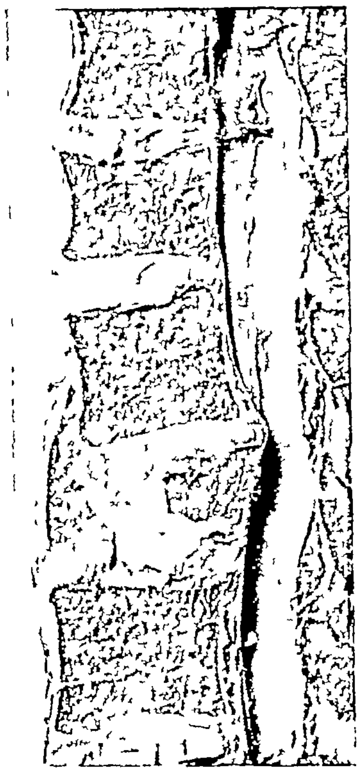


Fig 330 (left) Photograph of a sagittal section of the lumbar spine Woman, age 24 Compression fracture of the third lumbar vertebra, the neighboring discs have prolapsed into the vertebral body and are in contact (The fracture occurred six years before death) The anterior fragment shows a slight outward dislocation caused by pressure (preparation by Professor Geipel)

Fig 331 (right) Lateral radiograph of the preparation shown in figure 330

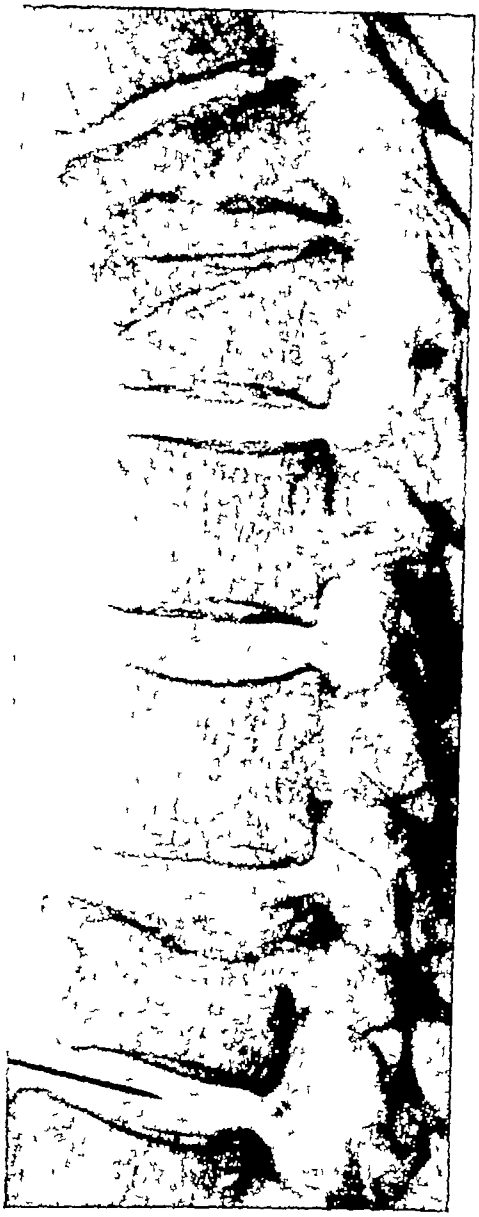


Fig 332 (left) Photograph of a sagittal section of the thoracic spine Woman, age 62 Compression fracture of the ninth thoracic vertebra The antero-superior margin of the tenth thoracic vertebra has entered the body of T 9 Rupture of the T 9 — T 10 disc The ruptured disc shows healing by sclerosis Small prolapse of the T 8 — T 9 disc into the ninth thoracic body after rupture of the upper cartilaginous plate of T 9 Minor compression fracture of the first lumbar vertebra The T 12 — L 1 disc indents the body and exhibits some prolapse posteriorly Extensive fissuring of L 1 — L 2 disc Schmorl's node, possibly traumatic

Fig 333 (right) Radiograph of specimen shown in fig 332 The irregular outlines of the disc space T 9 — T 10 point to a traumatic lesion of the disc The upper surface of the first lumbar vertebra shows double outlines Pin in the first lumbar disc

studies to broaden our understanding of the relationship between vertebral arch fractures and the associated disc lesions *Dislocations* of the small vertebral joints can occur only with serious concomitant disc lesions Radiographic studies carried out shortly after injury will not permit a diagnosis, which can be established only by the observation of the changes which make their appearance some time after the occurrence of the trauma

3. Healing and the sequelae of the healing process

The recognition of the sequelae of disc lesions is of particular clinical interest, not only because of the role played by the disc in the function of the spine, but because of the late appearance of these sequelae in radiographs made several months after the injury We have pointed out, previously, the considerable medicolegal importance of these clinical and radiographic manifestations

Systematic examination of spines obtained at autopsy not only permitted Schmorl to publish the first detailed description of recent disc injuries but also to carry out a careful study of the late sequelae of these traumatic lesions *Of great significance* is his finding that the highly differentiated tissues of the annulus fibrosus, the nucleus pulposus, and the cartilaginous plates are never replaced by like tissues after injury Even in such minor lesions as minute ruptures, fissuring of the annulus, loosening of the cartilaginous plate or detachment of the annulus from the bony rim, healing results from the appearance of fibrous tissue and cicatrization Since this process is accompanied by rearrangement of the lamellae of the annulus in the region of the injury, the affected disc loses its elasticity to a degree determined by the extent of the destruction and cicatrization Frequently, there is not only invasion of the fissures by vascular connective tissue but also appearance of deposits of calcium, cartilage and bone, as is seen in the healing process following degenerative changes (fig 335, p 165)

The presence of vascular tissue is essential to the repair of the injured disc Since the normal adult disc is avascular (p 12), the repair processes in the injured disc is produced by the proliferation of exogenous vascular tissue and is the result of injury to the bony or ligamentous structures It is possible, however, that the vascularization observed was not an immediate sequel to such an injury but had occurred following some previous trauma (*e g*, a Schmorl's node) and, thus, may represent the response of the disc to an earlier injury

Tammann's experimental studies using animals established the fact that the tissue of neither the nucleus nor the annulus can be reconstituted after trauma, and he observed that the lesions were healed by the formation of granulation tissue, followed by cicatrization and ossification Animal experiments by Lob produced similar findings and these will be considered in detail in the discussion of traumatic spondylosis deformans (pp 179, 196ff)

Filippe reports that lesions produced experimentally in the discs of animals heal with complete anatomic and functional restitution, but this contradicts our own experience as to both human and animal discs and must be confirmed by additional experimental work

Fig 334 (left) Lateral radiograph of a sagittal section of the lumbar spine Man, age 69 Compression fracture of the third lumbar vertebra The adjacent discs have extended into the vertebral body to meet in its center Extensive callus formation from the second to the fourth lumbar body Cloudy opacities (calcification) are seen in the L 3 — L 4 disc Narrowing of the intervertebral foramen

Fig 335 (right) Photograph of a sagittal section of the lumbar spine The third lumbar disc is thinned and partly replaced by bone tissue due to a traumatic compression of remote origin

The early repair processes of the injured disc are not demonstrable radiologically, and radiographic findings appear only when deposits of calcium or bone occur One must remember, however, that such deposits are not pathognomonic of a healing traumatic lesion, but are also seen in the degenerative changes Observations over a long period, with radiographs made at frequent intervals, will result frequently in a clear portrayal of the gradual development and growth of the bone deposits If no calcium or bone deposits occur, and if the healing process is limited to cicatrization by fibrous and vascular tissue, the disc lesion will not be demonstrated in the radiograph and its presence must be deduced from the narrowing of the disc space and its altered contour The evaluation of these late sequelae must be undertaken cautiously, however, since infectious processes also may alter the disc space (p 182)

Sometimes, small osteophytes will appear in the vicinity of an injured disc (figs 336 and 337), and these will be described in more detail in the chapter on traumatic spondylosis deformans (chapter V H) They are provoked by the abnormal mobility of the motor segment produced by rupture of the disc tissue In some instances, regression of the osteophytes may occur and may be demonstrable radiographically Such a regression follows the gradual cicatrization of the ruptured disc with rigidity of the segment replacing excessive mobility and with cessation of strain, and of the friction of the anterior longitudinal ligament and the vertebral body margin (p 192)

The invariable clinical sequel to cicatrization, with invasion of vascular and fibrous tissue and the occurrence of bone deposits, is a loss of the elasticity and resilience of the disc tissue and, in consequence, rigidity of the affected portion of the spine If only one or two discs are involved, the rigidity will scarcely be apparent on physical examination, but when the discs of a fairly large section of the spine have undergone cicatrization, the loss of mobility will be apparent clinically If a rather large

section of the spine becomes rigid after fracture of a single vertebral body, there is a strong likelihood that multiple disc lesions are present These changes may be demonstrated radiographically by the technic suggested by Knutsson This consists of lateral projections with the patient upright and with the shoulders weighted by sandbags, or by lateral radiographs with the spine in flexion and in hyperextension while the pelvis is immobilized (see functional radiography, pp 21, 22, 130 and 157) Thus one may demonstrate interruption of the normal spinal curvatures by angulation or by rigid sections Permanent alterations in spinal curvatures, following fractures, result not only from the presence of the fractured vertebra, but also from the post-traumatic disc changes

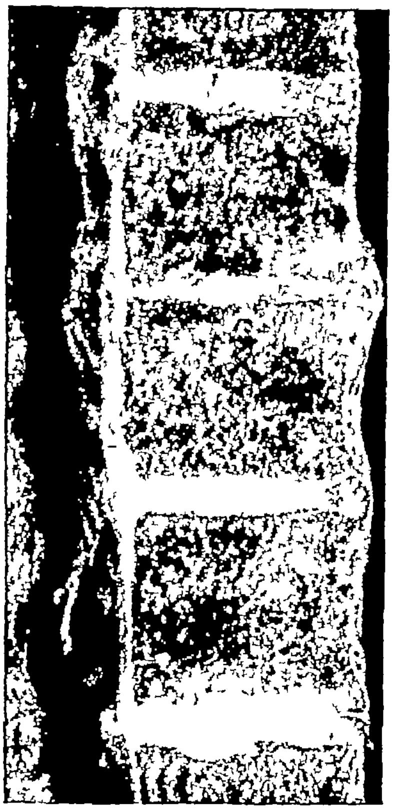


Fig 336 (left) Photograph of a sagittal section of the spine Woman, age 54 Anterior thinning of the T 9 — T 10 disc, subcortical cartilaginous node of traumatic origin Extensive sclerosis of the spongiosa adjacent to the compressed disc Upward expansion of the T 11 — T 12 disc in the region of the nucleus (cartilaginous node)

Fig 337 right) Lateral radiograph of the specimen shown in fig 336 Narrowing of the T 9 — T 10 disc space The anterior portions of both vertebral bodies show sclerosis and osteophyte formation The lower vertebral plate shows a small Schmorl's node surrounded by a bone envelope A Schmorl's node bulging deeply into the vertebral body and surrounded by a bone envelope is present beneath the inferior vertebral plate of T 11

Disc tissue which has entered a vertebral body following fracture may become fixed there during the healing process (fig 330), even if more or less surrounded by bone Usually, however, it undergoes more or less complete ossification with only vestigial remains of the original disc tissue Unfortunately, we lack histologic studies of these changes

The syndrome of delayed, post-traumatic vertebral collapse (Kümmell's disease, p 96) is sometimes observed as a late result of a traumatic disc lesion, and this has been emphasized by Lob The prolapse of disc tissue into the spongiosa may interfere with callus formation and decrease the weight-bearing capacity of the vertebral body until, gradually, complete collapse of the vertebra occurs We believe that the presence of nuclear fluid has an osteoclastic action and that this may be of importance Or, as Lob points out, if anterior or lateral prolapse of disc tissue occurs, with resulting decrease in the resilience of the disc tissue, the functional capacity of an injured vertebral body is markedly reduced with its subsequent collapse, although at first, it retained its normal height

4. Nonhealing and retarded healing of disc lesions and their sequelae

Healing of a traumatic disc lesion does not always occur as we have described it, and invasion of vascular and fibrous tissue, followed by cicatrization, may not occur for a long time and, perhaps, not at all If this is the case, the effect on the disc tissue and on the physiologic function of the spine is disastrous A disc lesion adjacent to a fractured vertebral body will, ordinarily, be followed by vascularization and cicatrization but, in isolated disc lesions, these changes may fail to take place.

resulting in abnormal mobility of the affected disc subjected to the usual movement and weight-bearing functions If the annulus fibrosus is torn, the intrinsic pressure of the nucleus pulposus forces it into the fissures in the annulus, but if the normal structure of the nucleus has been disrupted with loss of internal pressure, the annulus can no longer exercise its hydraulic-buffer function during movement of the spine Degenerative changes, extending from the region of the lesion, are an invariable and inevitable sequel It seems obvious that there is a close relationship between post-traumatic lesions, their sequelae and degenerative changes, but we are in need of more histologic studies if we are to understand fully the interrelation of trauma and degenerative changes (fig 201) If, sometimes, vascularization does not occur in an isolated disc lesion, there will be a gradual increase in the traumatic ruptures and fissures, and dessication of the nucleus and pulverization of the disc tissue in the area of the ruptures follow It is probable that Schinz had such sequelae in mind when he termed gradual disappearance of a disc "the fibrocartilaginous form of Kümmell's disease " We do not regard this designation as a suitable one since the term "Kummell's disease" applies to a post-traumatic lesion of a vertebral body (chapter III G 4)

Noncicatrization of a traumatic disc lesion may have varied and numerous results The steadily progressing narrowing of the disc space, recognizable in the radiograph, may result in complete obliteration of the space with contact between the adjacent vertebral bodies and the production of the pathologic state which Schmorl called "osteochondrosis " In chapter IV C 2 this is more thoroughly described in connection with degenerative changes in the disc tissue If this condition affects a single disc space, it is quite probably of traumatic origin Trauma, as an etiologic factor, is quite questionable when several disc spaces are involved

Solid bony union between two adjacent vertebrae (block vertebrae) may result, sometimes, from extreme destruction of the disc tissue, as has been shown by animal experimentation (Tammann) Confronted with a block vertebra, the differentiation between trauma and past infectious processes as the etiologic factor is quite impossible (fig 335)

Nonhealing of a traumatic disc lesion does not necessarily lead to complete destruction of the disc tissue, but may lead to the occurrence of spondylosis deformans which develops in the area of laceration of the disc (see chapter V G, cf p 178, chapter IV E 3)

Among the traumatic disc lesions we may include certain rare posterior disc prolapses which develop slowly after the occurrence of trauma (p 146) The nonoccurrence of cicatrization of a posterior or posterolateral laceration may permit, during certain movements, intermittent prolapse of disc tissue with resulting nerveroot pressure, and the subsequent return of the prolapsed fragment into the disc space, thus producing the clinical picture of posterior disc prolapse with intermittent signs of medullary and nerve root compression (fig 271) Thus, noncicatrization or delayed cicatrization may provoke an intermittent and delayed pain syndrome

In a previous section (p 177) we have called attention to the production of osteophytes on the vertebral body in the region of disc injuries, and have indicated the possibility of their regression These changes, quite obviously, are associated with the delayed healing of disc lesions since, when healing occurs promptly after the trauma, it is inconceivable that abnormal mobility could be of sufficient magnitude and of long enough duration to produce osteophyte formation

In the animal experiments mentioned earlier (p 177) the disc lesions which were produced without an associated vertebral body fracture were called "isolated disc lesions" and the writers regarded the healing process (the invasion of other types of tissues) as the typical healing of an "isolated disc lesion " Since, in all of these experiments, the disc lesion was produced by incision or puncture of the anterior longitudinal ligament, the results are not comparable, strictly speaking, with a true traumatic disc lesion The lesion produced in the anterior longitudinal ligament prepared the way for the invasion of vascular and connective tissue which followed promptly in every case The nonhealing or failure of cicatrization, previously described, and which is a frequent sequel to isolated disc injury in the human adult, did not appear in the experimental animals A sound evaluation is probably impossible by animal experimentation The animals employed for laboratory investigation are young and their intervertebral disc contains residual vascular tissue, making cicatrization possible, even though the anterior longitudinal ligament remains intact

Fig 338 (left) Photograph of a sagittal section of the lumbar spine Woman, age 65 Compression fracture of the third lumbar body The L 2 — L 3 disc has ruptured into the body and several cartilaginous nodes have formed Antero-superior sequestration of a small fragment The vertebral canal is somewhat narrowed

Fig 339 (right) Lateral radiograph of a sagittal section of the lumbar spine Man, age 54 Old compression fracture of the upper portion of the first lumbar vertebra with callus formation and sequestration of the anterosuperior fragment The vertebral plate is fractured and depressed somewhat into the body. A Schmorl's node has formed in the area of fracture of the vertebral plate

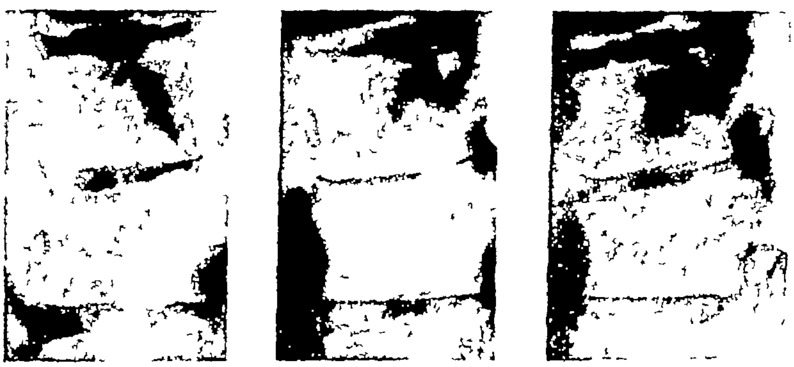


Fig 340 Lateral radiographs of the mid-thoracic region of a young man Films made in 1937, 1938 and 1940 The process of the formation of a traumatic Schmorl's node and the course of healing of a fracture of the vertebra is demonstrated

5. Schmorl's nodes and *trauma*

From our description of the nature and development of Schmorl's nodes (chapter IV B 1, 2, 4) it is apparent that they may develop suddenly following trauma, or *gradually* as the result of degenerative changes and preexisting congenital anomalies (figs 338 and 339) In certain cases of recent spinal trauma the anatomic specimen shows ruptures of the cartilaginous plate, fractures of the bone trabeculae with hemorrhage and prolapse of the disc tissue (figs 315 and 316) In such cases, the diagnosis of traumatic disc prolapse can be established Such traumatic disc prolapse may be recognized radiographically, however, only when the prolapse was of considerable volume and the vertebral plate was markedly depressed An interruption of the contour of the vertebral plate, sometimes recognizable radiographically, is indicative of disc prolapse Definite radiographic demonstration of a *traumatic Schmorl's node* requires that the film taken immediately after the injury shows normal outlines of the *vertebral plates*, while subsequent periodic studies reveal its gradual development (fig 340, Häbler, Rosler) A Schmorl's node may represent prolapse into a fractured vertebra, or at some distance from it, but also it may occur without actual fracture If a Schmorl's node is to be related to a given antecedent trauma (whether a fracture or not), it must be possible to *demonstrate, radiographically, that no node was present* before the trauma occurred The node may have developed independently from the trauma or may have existed prior to it These possibilities should be borne in mind and prudence should be exercised in medicolegal evaluation of such cases (figs 338 and 339) The original volume of a traumatic Schmorl's node may decrease as the pressure of the

disc diminishes (see p 141) Experimental studies of the pressure necessary to produce a Schmorl's node was carried out by Zsebök and others (Poglayen and Klein)

Stellate tears of the cartilaginous plates which occur frequently with severe contusions of the disc (chapter IV E 1, fig 313) favor the penetration of small fragments of the disc tissue into the subadjacent cancellous bone These fragments gradually transform into Schmorl's nodes

In one of his last publications Kummell was of the opinion that traumatic fibrocartilaginous nodes were responsible for delayed post-traumatic vertebral body collapse (chapter III G 4) It is quite possible that the prolapse of disc tissue into the fractured vertebral body delays healing Lob was of like opinion

Gellmann has observed the gradual development of Schmorl's nodes with irregularity of the vertebral plates following spinal puncture in a child Whether the injury by the puncture was responsible will require additional observations Bibliography Brandes, Buisson, Rose and Metzingen, Strang, Wissing et al

F. Infections

1. Primary infections of the disc

Vascularization of the disc is essential for the production of hematogenous infection In a child the disc is vascularized (p 12), but in an adult this is the case only when a pathologically changed disc is present Schmorl, in his serial studies, found a primary infection of the disc only in exceptionally rare instances (*e g*, small abscesses in the disc L 2—L 3 in a case of septicemia following tonsillitis) In the past it was believed that tuberculous and typhoid spondylitis begin in the disc and there are still those who support this opinion (Annovazi, Klar, Morasca, Strukow)

Fig 342 Photograph of a sagittal section of the thoracic spine Woman, age 20 Tuberculosis of the disc with abscess formation is shown The other portions of the disc are narrowed and are occupied by fibrous tissue

Fig 343 Radiograph of the specimen shown in figure 342 The disc space is narrowed and sclerosis has occurred in the vicinity of the abscess due to inflammatory changes

Fig 341 Photograph of the ventral surface of the spine Woman, age 49 Suppurative osteomyelitis of the spine The anterior longitudinal ligament has been elevated by a paravertebral abscess and the discs have been destroyed by the abscess

W Weber believes that the infections of the disc which originate in the subchondral area (marginal osteitis) do not represent an actual osteomyelitis of the vertebra, but should be considered as primary disc infections In such cases he advocated immediate surgical removal of the entire disc With this procedure, the healing process is accelerated and no special immobilization is required

Fig 344 (left) Lateral radiograph of the spine. Girl, age 5 Tuberculosis of the twelfth thoracic and first lumbar vertebra with destruction of the intervening disc The first lumbar vertebra has collapsed Minor kyphosis and narrowing of the intervertebral foramen are present Reactive osteosclerosis in the vicinity of the inflammatory process

Fig 345 (right) Lateral radiograph of a sagittal section of the thoracic spine Woman, age 54 Tuberculous destruction of the ninth and tenth thoracic bodies and of the intervening disc Cuneiform vertebra and gibbus deformity

The disc may become infected directly during spinal puncture (p 107) and 44 such cases have been collected (Bromley with Craig and Kistel) Infection of the disc with spread to the adjacent bone was observed following surgery for disc prolapse and after various diagnostic procedures (cf chapter III I 2, p 107) In the presence of an infected disc and vertebral body, lumbar puncture may initiate spread of the infection to the meninges with disastrous results (Knasko and Strotzka)

2. The intervertebral disc and spondylitis

Any destructive process of the vertebral body may invade the disc The cartilaginous plate is a sort of barrier, but once the disc has been invaded destruction progresses rapidly The disc may also be invaded by an extrinsic

Fig 346 Lateral radiograph of a sagittal section of the spine Woman, age 72 Tuberculous destruction of the first, second, and third lumbar bodies with extensive destruction of the intervening discs Collapse of the vertebral bodies and considerable narrowing of the disc spaces, gibbus deformity Due to the stimuli of the inflammatory process, osteoporosis has developed in the affected vertebral bodies Extreme narrowing of the intervertebral foramina

infectious process, as when an abscess extends along the anterior longitudinal ligament or in instances of wandering abscess, osteoperiostitis, or anterior superficial spondylitis (see p 103, fig 341, Kremer and Wiese, Mandelstamm) This path of the spread of infection is less frequent than that across the cartilaginous plate Destruction of disc tissue by infection results in narrowing of the disc space

Fig 347 (left) Photograph of a sagittal section of the thoracic spine Man, age 32 Old, healed tuberculosis of three thoracic vertebrae and the intervening disc An Albee operation (interspinous graft) can be seen

Fig 348 (right) Radiograph of the preparation shown in figure 347 Pin in the first lumbar disc Moderate sclerosis in the affected vertebral bodies Bone graft and the wire sutures can be seen

(figs 342 and 343), a characteristic feature, particularly, in Pott's disease (figs 344—348) Diffuse necrosis involving several segments was discussed in chapter III I, figures 188—191

These disc changes may occur in any form of spondylitis In recent years well documented radiographic studies of typhoid spondylitis have been published In these cases the primary focus of infection was thought to be located in the subchondral area (Lyon), the disc invasion occurring secondarily Scholz, Puhl and Gallus also believe that the primary foci of infection of typhoid spondylitis are in the bone close to the inferior and superior vertebral surfaces Histologic studies of the spread of infection across the cartilaginous plates are lacking

Radiographically, disc space narrowing due to an infectious process is observed before the appearance of destructive osseous changes (Carson, Zanoli)

The radiographic features of infection of the disc are discussed in detail by Bonhoure, Madelung, Quincke, Lyon, Puhl, Ellmer, Rostock, George and Leonhard, Doub and Badgley The irregularity

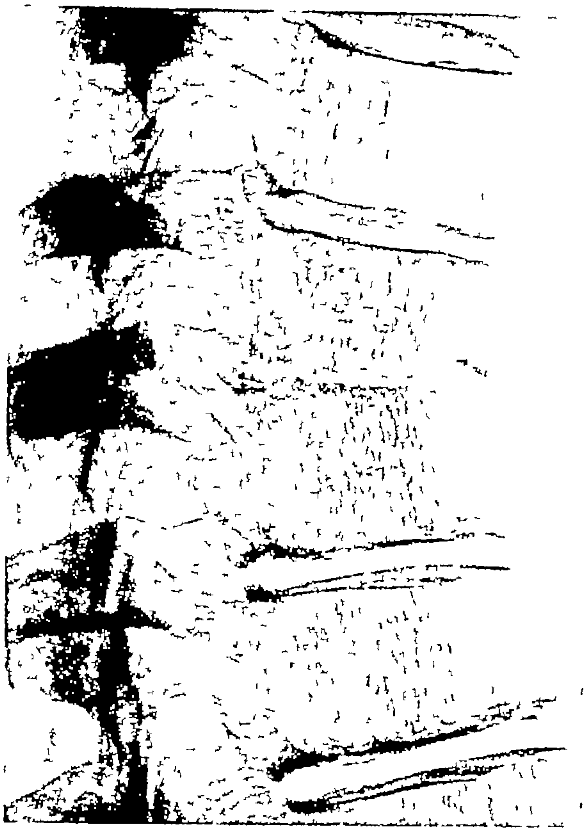


Fig 349 (left) Lateral radiograph of a sagittal section of the thoracic spine Man, age 58 One disc space has disappeared and bony fusion of the two neighboring vertebral bodies is beginning (early stage of formation of a block vertebra in healing tuberculosis)

Fig 350 (right) Lateral radiograph of a sagittal section of the lumbar spine Man, age 62 The third and fourth lumbar vertebral bodies have formed a block vertebra following old healed tuberculosis On section, tuberculous pus was found in a cavity deep in the block

of the contours of the vertebral plate is an important feature Occasionally, there may be clouding of the intervertebral space in the early stage of the infection

3. Postinfectious sequelae

The sequelae of a healed infection of the intervertebral disc are of particular interest The cartilaginous plate is usually destroyed and the disc invaded by fibrous tissue In one case of a healed Pott's disease we saw small caseous focus in a disc which had been transformed into sclerotic fibrous tissue The vertical diameter of the disc was markedly reduced (figs 342 and 343)

Fig 351 Photograph of a sagittal section of the lumbar spine Man, age 64 Extensive destruction of the third lumbar disc Cartilaginous proliferations in the disc vertebral borders, and condensation of the adjacent spongiosa are evident Slight spondylolisthesis of the third lumbar vertebra The anterosuperior edge of the fourth body has been severed

Ossification is another sequel, with resulting formation of a block vertebra, which resembles a post-traumatic block vertebra. The differential diagnosis on radiographic grounds alone may be extremely difficult (fig. 351, Büssem, Ellmer, Finder, Lyon, Rostock). Both post-traumatic and postinfectious sequelae affect the functional capacity of the spine more seriously when both the vertebral bodies and the discs are involved.

G. Neoplasms

We have never observed a primary tumor of a disc or a metastasis which involved only a disc. However, the disc may be invaded by primary or metastatic malignancy by extension from a neighboring structure (Nepi, Perotti). If the tumor is located in the vertebral body, it may invade the disc by destroying the cartilaginous plate, or it may extend through the openings in the cartilaginous plates (vascular, fissures, etc.). Occasionally, the disc and the body are eroded on one side (p. 121), as in aortic aneurysm (figs. 216–218).

In osteolytic vertebral metastasis one sees, quite commonly, that before invasion the disc expands and prolapses into the weakened vertebral body (fig. 258). Such a prolapse is not associated with any reactive sclerotic changes and consequently it escapes recognition by radiography. We were able to demonstrate such prolapse on radiographs of thin sections of anatomic specimens, but since this is of limited practical importance, we shall not reproduce these illustrations.

V. Spondylosis Deformans

Spondylosis deformans, as regards its frequency and its morphologic changes, is, perhaps, the most important of the various pathologic changes which involve the spine (Junghanns, Kümmel and Kautz, W. Müller et al.). Many theories have been proposed to explain the origin of the marginal osteophytes which occur on the vertebral bodies. Since Beneke and Rokitansky first called attention to the role of the intervertebral discs in the origin of this disease, their significance as a contributing factor has been widely accepted. In recent years spondylosis deformans has created considerable medicolegal interest, since its relationship to industrial accidents involving trauma to the spine is not easily established. There is now a definitive differentiation between spondylosis deformans* and the inflammatory diseases of the spine and, in the clinical literature, the term "spondylosis deformans" has generally replaced the earlier term "spondylitis deformans," making quite obvious the differentiation between the two lesions. In the following pages we shall review some of the more recent publications selected from the extensive bibliography on this subject.

A. Frequency

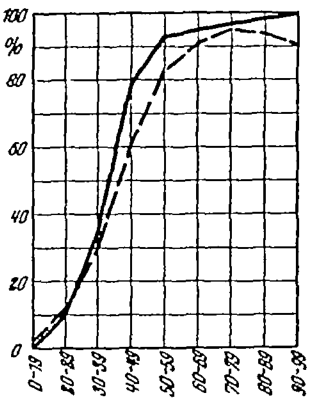
Reviewing the literature, one is struck by the numerous contradictory statements as to the frequency of marginal osteophytes. The largest anatomicopathologic statistical compilation (that of Junghanns) is based on the examination of Schmorl's collection of 4253 thoracolumbar spines obtained at autopsy, and demonstrates that sex differentiation is less significant than had been generally assumed (fig. 352), but the sharp increase in the steepness of the curve in both sexes and at various age periods is of great interest. For example, at age 49, 60 per cent of the females and 80 per cent of the males examined showed spondylosis, contradicting Heine (in the same Institute) who in 1926 found spondylosis in only 15.6 per cent of males and 24.3 per cent of females in the age group 40 to 49 years. It must be noted, however, that Heine counted as spondylosis deformans only those in which bony spurs were visible to the naked eye.

These anatomicopathologic statistics demonstrate a much higher frequency of occurrence than do clinical and radiologic statistics. Schürmann, quoted by Gantenberg, found bony overgrowth and spur formations on the vertebrae in 35 to 40 per cent of miners in the Ruhr. As an incidental finding in 1000 radiologic studies of the urinary tract, Garvin found that in patients more than 50 years old, 67 per cent of the males and 40 per cent of the females showed radiologically recognizable spondylosis deformans. The frequency of radiologically demonstrable spondylosis deformans in the cervical spine as reported by Bente with Kritschmer and Schuck is approximately that shown in fig. 352. Other statistics are reported by Asai, Gerlach and Kreissel, Tonnis and Gerlach. Differing from Heine who found no occupational relationship to the frequency of spondylosis deformans, Gantenberg noted marked differences in its occurrence in persons engaged in various occupations. Among 1200 persons examined radiologically, he found a particularly high incidence of moderate and severe form of spondylosis deformans in miners. It seems to be less common among factory workers, and even more uncommon among artisans. He also found spondylosis deformans to be much rarer and less well developed among the so-called "white collar" group. Beck found no significantly increased frequency of occurrence in the cervical spines of compressed air drill operators, and Mauntz reached a like conclusion as regards the lumbar spine.

Although Heine's statistics emphasize a sex difference, figure 352 shows a quite similar frequency for both sexes, and certainly Braun's contention that the incidence of spondylosis deformans is twice as great in males as in females is incorrect. The very low incidence of the disease in females observed by Gantenberg, and Schereschewski's observation that it occurs almost exclusively in males may well reflect simply the accidental composition of the materials examined. The differences observed between clinical and radiologic studies on the one hand, and anatomic studies on the other, simply reflect the fact that many small spurs, clearly visible to and easily palpable by the pathologist, are not demonstrable radiographically.

* In the American literature the term "osteoarthritis" is still frequently used to designate these changes (ed.)

A study of figure 353 is quite rewarding Note that the broken line shows that spondylosis with the lipping and spurring limited to the thoracic spine (in both sexes) is of more frequent occurrence in the younger age-group than in the older In the latter, moderate forms of spondylosis deformans of the thoracolumbar region are predominant Severe spondylosis deformans in the lumbar spine,



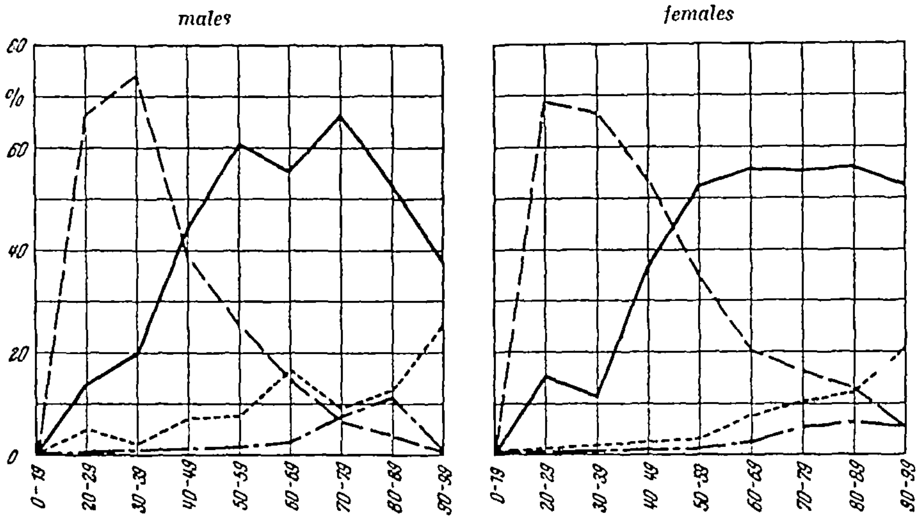


Fig 352 Frequency of spondylosis deformans in males and females of various age groups (males ————, females — — — —)

Fig 353 The distribution of spondylosis deformans in the lumbar and thoracic spine in various age groups of males and females

———— = minor involvement of the lumbar and thoracic spine
— — — — = thoracic spine affected without participation of the lumbar spine
- - - - - - - - = severe involvement of the lumbar spine with minor participation of the thoracic spine
—·—·— = severe involvement of both the lumbar and thoracic spine

with a lesser degree in the thoracic spine (dotted line), and also severe spondylosis in both lumbar and thoracic regions (dash-dot line) show a greater increase with advancing age Unfortunately, exact data on spondylosis deformans in the cervical spine are not available because, in the earlier studies, the cervical spine was not removed at autopsy Since the cervical spine has numerous points of difference as compared with the rest of the spinal column, a special study of this region including not only spondylosis deformans but fusion of the atlas and the occiput, spina bifida of the atlas, and the Klippel-Feil syndrome would be a very rewarding subject for a special investigation

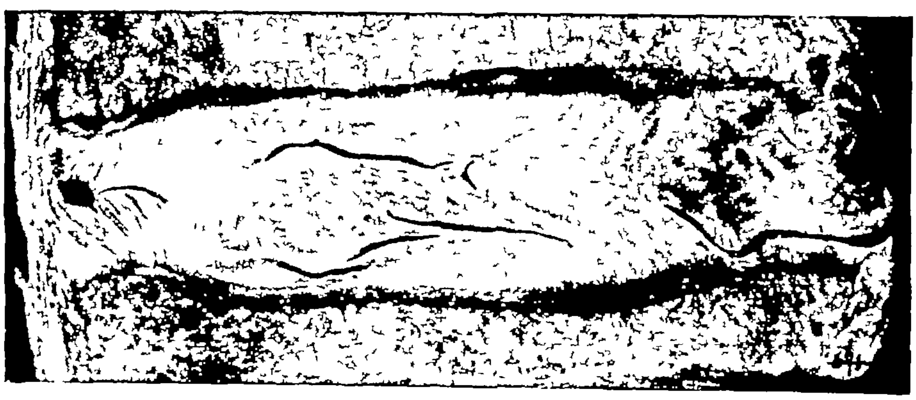


Fig 354 Slightly enlarged photograph of a sagittal section of a disc Anteriorly (on the right in the figure) the annulus fibrosus is detached from the bony rim and Sharpey's fibers are severed Anterior protrusion of the disc against the anterior longitudinal ligament Additional tears in the region of the nucleus pulposus can be seen

B. Etiology

After Rokitansky had drawn attention to the fact that disc degeneration and marginal overgrowths on the vertebral bodies appear concomitantly, R Beneke gave a detailed anatomic description of spondylosis deformans In his opinion, degenerative processes in the discs, especially in the nucleus pulposus (brown softening, disintegration, etc) cause a loss of elasticity and, hence, nonphysiologic stresses in the ligamentous apparatus, engendering proliferations, i e , marginal overgrowths arising

from the areas of attachment of the ligamentous apparatus For a long time this explanation was regarded as valid and was accepted as an unimpeachable basis for approach to the anatomic and clinical problems presented (W Müller, Übermuth, F Lang and others) Übermuth believes that spondylosis deformans begins with the first degenerative changes occurring in the cartilaginous plates (areas of nonossification, vascular scarring, etc), while Lang thinks it a chronic, infectious and productive type of inflammatory process involving the vertebral column He lays particular emphasis on the fact that because of diminished elasticity of the disc tissue, the functional stresses of weight-bearing and movement are transferred directly and undistributed to the adjacent bony plates As a result, there occurs vascular, medullary and bony proliferation which may be considered as the expression of "spondylitis deformans " If this explanation were correct it would seem logical that the more marked the destruction of the discs (involving a greater loss of elasticity), the more severe should be the spondylosis deformans This, however, is not the case In most cases of marked marginal overgrowths, which constitute a typical feature of spondylosis, only limited degenerative changes of the discs are found and the nucleus pulposus is comparatively well preserved Marked degenerative changes of the discs are usually associated with insignificant osteophyte formation In such cases sclerotic changes of the vertebral plates predominate (osteochondrosis, p 163, fig 300)

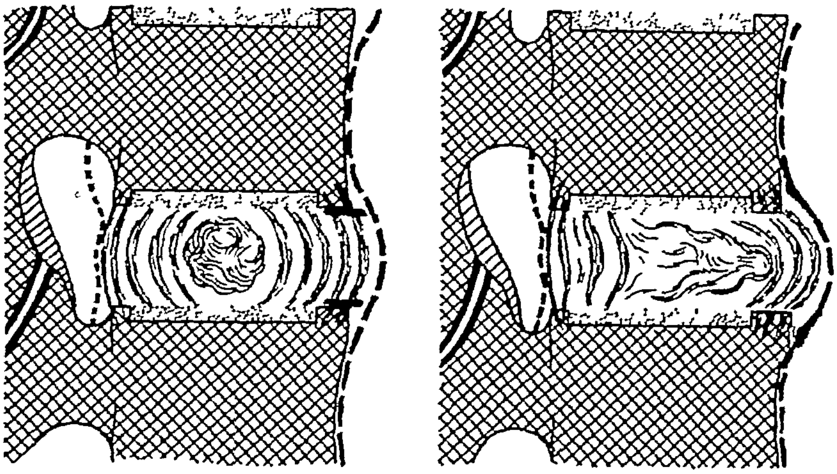


Fig 355 Schematic presentation of the development of spondylosis deformans As the result of the separation of the fibrous annulus and the severance of Sharpey's fibers, the annulus fibrosus is detached from the bony rim (red lines in the figure on the left) and the loosened disc prolapses anteriorly against the anterior longitudinal ligament Osteophytes are forming at the site of the detachment of the anterior longitudinal ligament at the point of its insertion (red lines in the figure on the right, cf figs 22, 356—358)

Fig. 356 Microphotograph of a sagittal section of the anterior portion of the disc Beginning spondylosis deformans with a tear in the rim annulus and with separation of the disc from the bone Protrusion of the disc Sclerosis of the spongiosa in the region of the vertebral body edges Small beginning osteophyte in the upper portion and a larger one in the lower portion

Since the experimentally proven facts could not be coordinated with the opinions hitherto held as to the origins of spondylosis deformans, Schmorl studied this problem with especial zeal during the latter years of his research activity and reached important conclusions as to the explanation of the problem under consideration In his view, the actual degeneration of disc tissue does not cause the marginal overgrowths, he

believes, rather, that spondylosis deformans is initiated by a typical tear in the region of the rim annulus (Schmorl gives the name "rim annulus" to the outer layers of the fibrous ring which radiate into the bony rims as Sharpey's fibers) When the fibers of the rim annulus become detached from the bony rim to any considerable degree (figs 354—356), solidarity between the vertebral body and the disc is lacking and nonphysiologic movements occur

The supporting function is taken over by the anterior longitudinal ligament and, as the result of overstrain, bony spurs develop (figs 355 and 356) in the areas of its attachment (fig 22) Due to its intrinsic tension, the nucleus pulposus, if not yet degenerated, presses the detached disc tissue outward, thus subjecting the anterior longitudinal ligament to more stress, and produces increased tension in the areas of attachment If, however, the pressure of the nucleus pulposus is diminished as the result of degeneration, there occurs less strain on the anterior longitudinal ligament

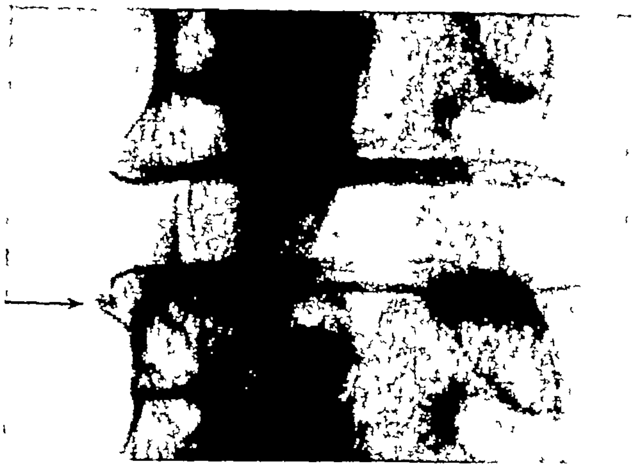
The results of Schmorl's investigations have confirmed the basic opinion of Beneke and others that the cause of spondylosis deformans lies in the discs and not in the vertebral bodies, although the previous assumption that disc degeneration was the actual cause was incorrect Schmorl demonstrated that the severance of the rim annulus from the bony rim initiates the onset of spondylosis deformans Destruction of the annulus fibrosus at the level of its radiation into the bony rim must be conceived as a frequent, typical and special form of disc degeneration included in the general definition of chondrosis intervertebralis (chapter IV C 1) The fact stressed by Beneke, F Lang, W Muller et al that incorrect functional strain, wrong distribution of pressures, etc , cause the development of the marginal overgrowths and the progress of spondylosis deformans is in agreement with Schmorl's explanation of the cause of spondylosis The severance of the rim annulus, (if unaccompanied by functional strain of the spine produced by weight-bearing and movement) does not lead to a material spondylosis deformans On the other hand, particularly severe spondylosis deformans is found in persons doing heavy work (Gantenberg et al), and this is regarded as a sequel to constant overstrain with the detachment of the rim annulus as the preliminary cause (see also the section on trauma and spondylosis deformans, p 196) Beneke and Simmonds also explain the more severe involvement of the right side of the thoracic spine as a result of greater strain from being right-handed As a matter of fact, in the Dresden material, more severe overgrowths on the left side of the thoracic spine were found in left-handed persons Schanz attributes the less marked involvement of the left side of the thoracic spine to the presence of the aorta, which, he thinks, acts as a supplementary support of the spine on this side In Plesmann's opinion, the intrinsic pressure in the aorta prevents the formation of marginal overgrowths in that area (For spondylosis deformans in amputees, in spines with postural scolioses, and that resulting from military service connected injuries, see p 197)

The causes of spondylosis deformans have been studied by many other investigators In Podkaminsky's opinion the pH of the fluid content of the gelatinous nucleus is decreased, resulting in a decrease in the function of the removal of decomposition products, leading, in turn, to degeneration Plate assumes an infection damaging the resistance of the bone, and Tapia and Valdivieso believe that infectious processes may play a part Seiffert and Schmidt-Kehl were able to show definitely, by the staphylolysin reaction, that there is no staphylococcal infection in spondylosis deformans Klinge believes that some forms of disc degeneration are of rheumatic origin and that this may be one of the causes of spondylosis deformans Ober claims an infectious origin, while Schuller assumes an inflammatory basis and suggests the name of "Perispondylitis " He arrives at this opinion by radiologic study without anatomicopathologic examinations Congenital factors are believed to play a part (Landwehr), Kemp with Murray and Wilson consider that fluorosis and general nutritional conditions are determining causative factors in spondylosis deformans

Solitary osteophytes on the vertebral bodies have been regarded sometimes as the expression of disease in adjacent structures (such as, renal disease, etc) Jacobiwici and Jiano believe that they may be explained by unusual functional muscular stresses which spare one group of muscles at the expense of another These questions, as well as the assertions, common in the clinical literature, that isolated marginal overgrowths on the vertebrae may occur at the site of a cord tumor require further study

C. Anatomic and radiologic aspects

The detachment of the rim annulus from the bony rim, described by Schmorl, can be recognized readily microscopically on sections cut in the sagittal plane The rim annulus of the disc may be severed from both adjacent vertebrae but, sometimes, is detached from only one vertebral body



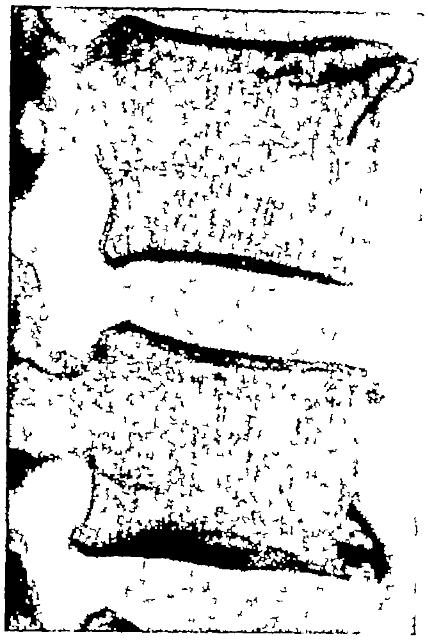


Fig 357 (left) Anteroposterior radiograph of the lumbar spine Man, age 60 A small osteophyte (arrow) just below the vertebral margin, at the junction of the bony rim with the vertebral body

Fig 358 (right) Lateral radiograph of a sagittal section of the lumbar spine Woman, age 60 A beginning osteophyte at the site of the insertion of the anterior longitudinal ligament (cf fig 355)

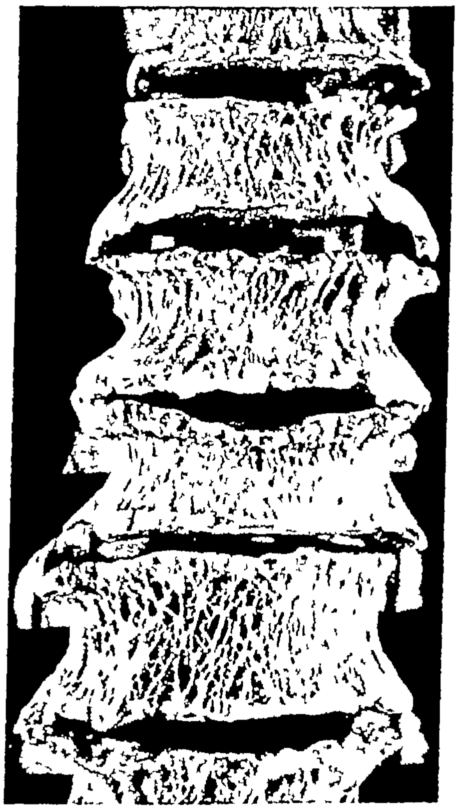


Fig 359 (left) Photographs of two vertebrae made from different angles Man, age 45 Beginning spondylosis deformans The bony rim is intact

Fig 360 (right) Photograph of the macerated lumbar spine Man, age 73 Frontal view Numerous large and small osteophytes of the vertebral bodies, with distinctly raised bony rims (ossified strands of the anterior longitudinal ligament) extending along the surfaces of the vertebral bodies

However, the detachment is of pathologic significance only when it involves the whole width (*i e* , from the anterior edge of the rim to the anterior margin of the cartilaginous plate), because only then can an actual outward prolapse of the disc take place This outward pressure on the disc, previously recognized by Beneke, may, in some cases, engender proliferative processes Embeddings of disc tissue are found between the marginal overgrowths, due, in part, to an active proliferation of disc tissue and, in part, to the presence of remnants of a prolapsed disc (Schmorl)

It has already been mentioned that these overgrowths, which constitute the most striking macroscopic feature of spondylosis deformans, and which are recognizable radiologically, are not located on the actual edge of the vertebral body They arise on the exterior surface of the vertebral body where the vertebral body and the cartilaginous rim meet during the period of growth (fig 22) From this, Luschka concluded that the osteophytes originate from the remnants of the cartilaginous rim, but this opinion can be disproved easily, since the marginal overgrowths develop only after the completion of growth, when the cartilage is no longer present Marginal osteophytes develop in the area just described because this is also the site of the insertion of the anterior longitudinal ligament (see p 16, fig 22) As we know, the anterior longitudinal ligament spans the disc and vertebral rims and is attached to those structures by only a few fibers It is firmly attached to the external surface of the vertebra just below the rim (between the superior and inferior rims of the vertebral body) and marginal osteophytes develop exactly in the area where the longitudinal ligament spanning the rim becomes firmly attached to the vertebral body (figs 357—359) This is because the stress and strain from the pressure of the disc tissue and the effect of nonphysiologic movements

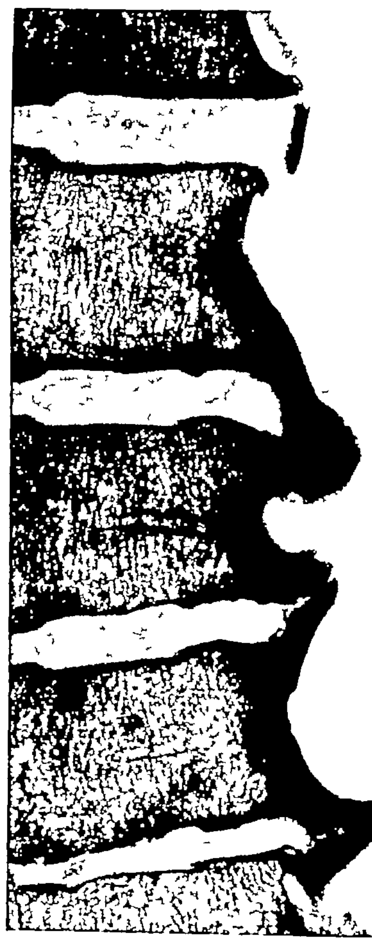


Fig 361 (left) Lateral radiograph of a sagittal section of the spine Man, age 69 "Pseudocysts" (arrows) in the vertebral bodies in a case of extreme spondylosis deformans with spanning and overhanging osteophytes and concomitant atrophy of the vertebral bodies ("waist retraction")

Fig 362 (right) Lateral radiograph of a thin sagittal section cut from the thoracic spine Man, age 76 Extensive bridging and marginal overgrowth, formed by dense bone, is seen on all the vertebrae Pseudoarthroses between the margins Interposed bone is seen in front of the uppermost intervertebral space

become operative there Frequently, one observes on the anterior surface of the vertebrae small bony spurs joining the marginal osteophytes, and these represent the calcified fibers of the anterior ligament (figs 360 and 364)

The osteophytes of spondylosis deformans may develop into gnarled bony protuberances (figs 362 and 364), spanning the disc spaces in bizarre shapes and extending onto the vertebral body surfaces This is sometimes accompanied by severe atrophy of the vertebral bodies with retraction of the exterior surfaces of the bodies producing the so-called "hourglass" form This and the bridging osteophytes lead to the formation of hollow spaces which have the appearance of cysts on a radiograph Hammerbeck describes in detail an impressive case of this type (fig 361) and W Muller presents a similar case In extreme cases, the marginal osteophytes of the neighboring vertebrae may show bony union or may form a joint-like space at the point where they meet Occasionally, an isolated bone is interposed between two such osteophytes (Schmorl, Niedner, fig 362) Ott uses the term "hyperostotic spondylosis" for these forms The surface of the fused osteophytes is smooth and the bony trabecular network shows signs of rearrangement (figs 366 and 367) At a first glance this may be mistaken for ankylosing spondylarthritis (fig 366) and the diagnosis becomes more difficult if ankylosing spondylarthritis develops in connection with spondylosis deformans (fig 367)

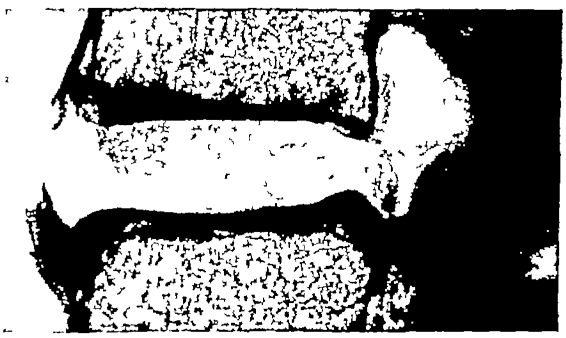


Fig 363 (left) Lateral radiograph of a sagittal plane of the lumbar spine Man, age 82 Moderate osteophytes arising from an area somewhat distant from the actual vertebral body so that it projects in front of the intervertebral space

Fig 364 (right) Frontal view of the macerated cervical spine Man, age 70 Extreme lipping, partly bridging the intervertebral spaces Ossification of the ligaments

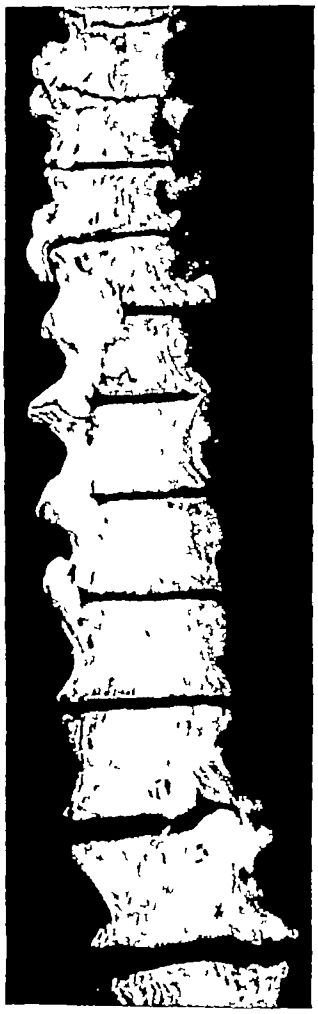
It must be stressed that when the vertebral bodies exhibit firm union (by fibrosis, disc ossification, etc), spurring and osteophyte formation do not develop Frequently, one can follow radiologically the gradual disappearance of the lipping and spurring which originally arose as the sequelae of abnormal mobility (as in adolescent kyphosis, senile kyphosis, etc), occurring when the vertebral column has become rigid and when there are no longer any pulling and shearing stresses on the ligamentous apparatus (fig 393)

Spondylosis deformans of the cervical spine has a few particular features (fig 364, Kuhlendahl and Kunert) Schingnitz estimates that 40 per cent of people have some degree of spondylosis of the cervical spine, a figure comparable to the average frequency of occurrence in the thoracic and lumbar column Barsony, A Fischer, Grashey, Kienböck and Ober have studied the radiologic aspects of cervical spondylosis, the occurrence of which in this area appears to be rather high Osteophyte formation leads to narrowing of intervertebral foramina and to pressure on the emerging nerve roots with resulting symptoms (Goette, Löw, Morton, Ryden, and others) The osteophytes of the small joints of Luschka frequently lead to serious clinical manifestations (Krogdahl, Giraudi, Torgersen) largely in connection with disc prolapse (p 147) However, there is not much anatomic

evidence as to the role of arthrosis deformans in these hemiarticulations and as to its etiologic relation to disc prolapse Some investigators have reported that lipping and spurring of the cervical vertebrae may cause difficulty in swallowing or may result in narrowing of the trachea (Falk, Holmgren and Hellmer, Kertzner, Perotti, Spitzenberger, and Wiethe)

Degenerative changes, very similar to human spondylosis deformans, have been produced experimentally in animals (by destruction of the intervertebral discs, detachment of the rims, etc (cf p 179, Keyes and Compere, Lob, Schrader, Tammann) Osteophyte formation also occurs on the vertebrae of domestic animals, but detailed anatomic studies are lacking

There are no detailed investigations regarding the lapse of time necessary for the formation or the growth of these marginal overgrowths According to Heinrich and Städter it takes at least 18 months for the formation of a noticeable spur However, there is no doubt that following spinal injury beginning marginal overgrowths have been observed within four to eight weeks (Ellmer,



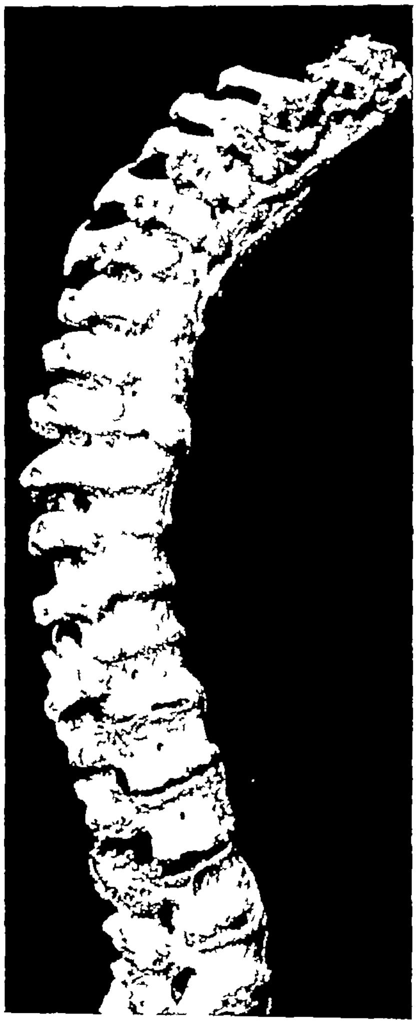


Fig 365 (left) Photograph of a sagittal section of the macerated spine of an old man Bridging marginal overgrowths on all vertebral bodies Rearrangement of the trabecular network in the vertebral bodies

Fig 366 (center) Photograph of the frontal view of the macerated spine Woman, age 76 Osteophytes on numerous vertebral bodies in the mid-portion of the thoracic spine on the right, and of the lumbar spine on the left The upper osteophytes show a smoothened surface, resembling a cake icing

Fig 367 (right) Lateral view of the macerated spine of an elderly person Extensive spondylosis deformans showing smooth surfaces bridging the intervertebral spaces The associated ossification of the costovertebral joints indicates that ankylosing spondylitis has supervened

Fenster, Haumann, Lob, Jäger, and Nicolas) This fact is of importance as far as traumatic spondylosis deformans is concerned (p 196) In a generalized spondylosis *it is not possible to evaluate the* time elapsed between the beginning of the disc lesion (detachment of the fibrous annulus) and the first appearance of the marginal overgrowths The time between the first signs of lipping and spurring which may be observed radiographically and the noticeable enlargement which finally leads to the spanning of the whole disc space varies greatly, and the importance and extent of the osteophyte formation depends on the initial disc lesion and on the subsequent strain and stress to which the spine is subjected

It is not known whether the spurs cause pain Bick considers it possible because Lindblom found *numerous terminations* of sensory nerves in the ligaments in which the spurs are formed Müller-Stephan has attempted to demonstrate the difficulties of the establishment of spondylosis as a clinical entity

D. Atypical osteophytes

Sometimes the spine shows osteophytes which are atypical as to their location and the mechanism of their formation They do not arise at the junction of the bony rim with the vertebral body proper but originate from the rim itself Pulling and tearing of the anterior longitudinal ligament cannot be considered as the cause of osteophyte production, since the ligament does not insert in the rim This type of osteophytosis is seen in cases with absorption of the discs Friction between the adjoining rims leads to the formation of reactive lipping and spurring, especially in senile kyphosis The same mechanism is operative in tabetic spines (fig 299), since here, too, there is friction between the neighboring vertebral bodies as a result of extensive absorption and degeneration of the discs (Stucke) Hypertrophic lipping on the uncinate processes of the cervical spine deserves particular attention (p 147, fig 274)

The well-known formation in infectious spondylitis (tuberculous, typhoid, etc), frequently mentioned in the literature (Haselhorst, Puhl, Rummel, Ulrich, etc), have nothing in common with true spondylosis deformans Detailed microscopic examinations will be needed to determine whether this spur formation and lipping must be conceived as a sequel to the infectious process leading to destruction of the disc and to the subsequent abnormal movements leading to tears of the ligaments, or whether the infectious process simply acts as a stimulus to new-bone formation In any case, it will be appropriate to separate the spur formation and lipping of the vertebrae associated with the infectious process from the actual spondylosis deformans

E. Osteophytes protruding into the neural canal

It is remarkable (although not always sufficiently emphasized) that even with very extensive osteophyte formation on the anterior and lateral margins of the vertebral bodies, the presence of osteophytes on the posterior border (*i e* , protruding into the neural canal) is quite rare Even when present, they are usually quite small as compared with similar formations on the anterior and lateral aspects of the vertebra The explanation of this curious fact is that the posterior longitudinal ligament has its major attachment to the intervertebral discs and is attached to the vertebral body by only a few fibers This ligament passes over the slightly concave posterior surfaces of the vertebral bodies, and the stresses regarded as a prime factor in the production of marginal overgrowths do not appear to occur on the posterior surfaces

There occur, at times, small osteophytes on the posterior vertebral margins even extending into the neural canal and these may be demonstrated in a good radiograph in the lateral projection (figs 272 and 273) Their presence adds a complication in the differential diagnosis of cervicobrachial or lumbosacral radiculitis With or without a concomitant prolapse of a disc, these bony formations may compress the nerve roots, either unilaterally or bilaterally In anatomic preparations, small button-shaped osteophytes have been seen and it seems certain that these posterior osteophytes are the result of disc lesions The most logical explanation seems to be that loosening of the disc results in abnormal mobility, and that the osteophytes are formed as a reaction to the abnormal

stresses imposed on the outer layers of the annulus fibrosus at the point of its attachment to the vertebral rim With the complete disappearance of the disc (osteochondrosis, chapter IV C 2), the development of the posterior marginal overgrowths is stimulated by friction between the bony margins This is more frequent at the lumbosacral junction since the intervertebral space at this level is normally attenuated in its posterior aspect, and with any marked decrease in the width of this space, the posterior vertebral edges come in contact with each other (figs 232, 233 and 272) Occasionally, the bony excrescences on the posterior surface of the vertebra or the anterior wall of the vertebral canal are due to ossified "posterior Schmorl's nodes" (p 143, figs 266 and 267) Actually, the posterior osteophytes should be excluded from the usual disease picture of spondylosis deformans since they presuppose special causes of origin It is, therefore, doubtful whether one may consider spondylosis deformans as being any part of the etiologic factors in nerve root syndromes This seems to be an assumption sometimes encountered in the literature (Braun, Junghagen, Kienböck, Krabbe, v Rad et al)

Bony spurs on the posterior wall of the vertebral canal have been observed frequently in our serial examinations (figs 220—222) They arise from the small joints or from the ligamentum flavum We have been unable to determine whether they lead to compression of the nerve roots and the spinal cord Further clinical experience and additional anatomic study is essential to the solution of this problem

F. Differential diagnosis

It is often said in the literature that it is not always easy to differentiate spondylosis deformans from ankylosing spondylitis (Marie-Strümpell's disease) This may be true for early cases (Assmann, Schwanke), but fully-developed cases of ankylosing spondylitis are characteristic and cannot be mistaken for the marginal overgrowths of spondylosis deformans, either in the radiograph or in the anatomic specimen The differential diagnostic aspects will be discussed in detail when dealing with ankylosis of the spine (p 196ff)

Occasionally, in cases of extensive spondylosis deformans, one finds osteophytes with smooth surfaces bridging one or more intervertebral spaces and closely resembling slightly protruding ossifications of the longitudinal ligament or long-standing ankylosing spondylitis If the differential diagnosis is difficult, a close inspection of the small vertebral joints and the costovertebral joints (which are almost regularly affected in ankylosing spondylitis) will be of help in arriving at a diagnosis (figs 347 and 407) Smooth marginal overgrowths form when the bridging osteophytes lead to complete rigidity Then the bone proliferations, which were at first irregular, become smooth, as does excessive irregular callus repairing a fracture, and which, after union is firm, becomes smooth by absorption and reconstruction Rokitansky and Wenzel compare such osteophytes to a mold

In the literature, one frequently finds spondylosis deformans and arthrosis deformans considered as related conditions Heine has shown that in nearly all subjects of advanced age, the changes of arthrosis deformans (erosion of cartilage with varying degrees of marginal lipping) are found in the large joints, particularly in the knee joint In view of this, it is difficult to evaluate objectively what is common and what is discrepant in those two conditions For the purpose of our investigation, the connection between spondylosis deformans and arthrosis deformans of the small vertebral joints is of special importance We will only say here that we have studied spines showing extreme spondylosis deformans and minor arthrosis of the small joints, as well as spines with distinct arthrosis of the small vertebral joints and insignificant marginal overgrowths of the vertebral body edges There certainly exists some relationship between the two disease entities since both are due to wear and tear, the vertebrae, however, with their discs, neural arches and small joints are subject to different mechanical stresses and, consequently, varying degrees of spondylotic changes of the vertebrae and arthrotic changes of the small vertebral joints are found with each change influencing the other Extreme spondylosis deformans with rigidity, for example, leads to immobilization at the level of the neural arches, which is certainly not without significance for the arthrosis deformans of the small vertebral joints, and vice versa The explanation of the interrelation of the two conditions, when both involve the same "motor segment," will require additional investigation

G. Spondylosis deformans and trauma

The question of the relationship between trauma and spondylosis deformans has been dealt with extensively in the literature Three questions are to be answered Does traumatic spondylosis deformans exist without vertebral fracture ? Does traumatic spondylosis deformans occur in connection with a vertebral fracture ? Can an existing generalized spondylosis deformans be exacerbated by trauma ? These questions have been subject to sharp dispute They continue to be a controversial problem and are frequently the subject of medicolegal controversies This shows with particular clarity that neither the pathologist, the clinician nor the radiologist can make the final decision alone The radiologist is able to follow the course of the formation of the marginal overgrowths, but only close cooperation with the clinician and the pathologist will advance our knowledge

Traumatic spondylosis deformans without a fracture of the vertebra is quite possible This has been shown by animal experiments (with disc lesions), carried out by Lob, Schrader et al , but their interpretation depends on the validity of the extrapolation of the results of animal experimentation to human beings, considering the different anatomic structure at the level of the body disc unit and the young age of the animals employed A given trauma in a human subject may also give rise to tears in the rim annulus followed by lipping on the adjacent vertebral body X-ray examination of such cases on the day of trauma will reveal no change whatsoever, but in from four to eight weeks, marginal overgrowths will begin to appear Frequently, there is an associated decrease in the width of the intervertebral space This type of traumatic spondylosis deformans without a vertebral fracture is commonly confined to a single vertebra or a few neighboring vertebrae (circumscribed traumatic spondylosis deformans) It may appear, however, in various spinal regions, just as separate fractures of more than one vertebra may occur (p 174) A generalized spondylosis deformans of the entire spine developing shortly after a spinal trauma in a spine which showed no radiographically demonstrable changes on the day of the trauma has not as yet been proven It can hardly be expected that such a case will be found, since it is inconceivable that any injury could affect the discs of the entire spine when they were intact prior to the injury A blow to the back, a fall on the back, hyperflexion or hyperextension, lead to corresponding disc lesions in a limited segment of the spine In the case of an extensive spondylosis deformans developing after a trauma one must think of the possibility that considerable degenerative changes in the annulus fibrosus were pre-existing Since traumatic lipping and spurring have been proved to develop rapidly, the traumatic origin of spondylosis deformans should be accepted only when distinct marginal overgrowths appear within the first six months after trauma in a spine which showed no noticeable changes prior to the accident Each individual case requires strict scrutiny

A traumatic spondylosis deformans with or without a vertebral fracture may appear if the trauma results in rupture of the fibers of the rim annulus of the involved vertebral body or a neighboring one This form of traumatic spondylosis deformans also will be, commonly, a limited one ("in the region of the fracture") According to recent radiologic investigations, its development occurs in the first months after the trauma (Heublein) However, differentiation between callus formation and ossification of the torn-off and vascularized longitudinal ligament remains difficult Some workers will speak of callus formation only if lipping occurs in the vicinity of the vertebral fracture (Gaugele et al) This view seems too limited for it does not sufficiently take into account the newer knowledge of disc lesions Certainly, in some cases one must think of the possibility of spanning and spurring occurring as a mechanical buttressing of a healing vertebral fracture On careful examination of the radiographs, a limited traumatic spondylosis deformans without a vertebral fracture (resulting from lesions of the annulus fibrosus) is frequently found at some distance from a vertebral fracture and represents lipping following trauma to a disc (Heublein) If radiologic examination carried out on the day of injury showed no demonstrable changes, the subsequent appearance of spondylosis deformans must be considered as being the direct result of trauma It has as yet not been explained sufficiently how much the various types of vertebral fractures (p 86) prevent or favor the formation of spurring and lipping

Sometimes, an old vertebral fracture is considered as responsible for a slowly developing generalized spondylosis years after the accident As an operative mechanism it was suggested that partial

rigidity in the region of the healed vertebral fracture resulted in changed mechanical conditions sufficient to account for gradual detachment of the rims of all of the discs ("the static spondylosis" described by Ruge) This appears to be a very questionable view, not justified by experience, as spondylosis deformans is present in nearly all persons with advancing age as the result of wear and tear (Junghanns) Evidence that a generalized spondylosis deformans gradually appearing after a vertebral fracture is a sequel to trauma can be found only in very rare and exceptional cases, *e g*, in a young subject with a significant post-traumatic deformity and only when the spondylosis deformans develops in the region of the fracture within a comparatively short time In general, however, few vertebral fractures lead to an obvious generalized spondylosis deformans, even after a deformity has existed for years

The possibility of a generalized spondylosis deformans being exacerbated by trauma cannot be overlooked Trauma affecting a spine with spondylotic changes with or without fracture may lead to further loosening of the annulus fibrosus which was affected by the trauma, followed by bulging of the disc tissue, change in the direction of functional stresses, pain-conditioned changes in posture and similar effects unfavorably affecting the already existing spondylosis deformans It is evident that in such cases an opinion will be difficult from a medicolegal standpoint To establish the relationship of a given trauma to the observed spondylosis deformans, one must demonstrate radiographically the rapidly occurring aggravation of the objective findings after the accident, considering carefully the extent and nature of the pre-existing lesions After 6 to 12 months the process takes a physiologic course (In Lob's material comprising 265 spinal injuries, objective evidence of exacerbation of generalized spondylosis deformans could be shown in 10 per cent of the cases)

It is quite clear that the multiple minor traumatic incidents of everyday life and the hazards of particular occupations may affect unfavorably an existing spondylosis deformans, just as it may be affected by a single major trauma We are lacking, however, in definite proofs, and the concept of spondylosis deformans as an industrial hazard of certain occupations (as suggested by Boidi-Trotti) does not seem to be a sound one, even though R Arnold is very much in favor of it Buetti-Bäuml found frequent involvement of the cervical spine, particularly in athletes Based on extensive investigations, Beck, Maintz, and others found no involvement of the cervical spine in workers with compressed-air drills

Long-enduring abnormal stresses applied to the pelvis and the lower extremities, such as occur in paralysis, malformations of the legs and pelvis, ill-united fractures and amputations of the lower extremities, with or without prosthesis, may be possible causes of spondylosis deformans Lumbar scoliosis resulting from permanent deformity of the pelvis leads to permanent overstrain of the discs located at the crest of the scoliosis and cause the formation of osteophytes (pp 138, 189) When the primary lesion (*i e*, amputation, severance of a nerve, etc) is the result of an accident, then medicolegally the resulting spondylosis should be recognized as being traumatic Lumbar scoliosis following amputation of a leg has been demonstrated by Jenny and Aufdermauer Arens considers that in a leg amputee the lumbar scoliosis is a compensation for the shift of the center of gravity and that in 50 to 66$^2/_3$ per cent of disability cases the changes of the spine are considered as part of the disability Quite plainly, a medicolegal appraisal remains difficult considering that spondylosis deformans is almost a physiologic phenomenon after a certain age (p 186) To follow the eventual development of spondylosis deformans in all cases of leg amputation would throw a good deal of light on the whole subject, since it is only thus that we shall be able to differentiate the post-traumatic findings from physiologic spondylosis It is particularly difficult to appraise the influence of military service-connected injuries to spondylosis deformans (Junghanns, Slauk, and others)

Occasionally, radiographs and anatomic specimens show "fracture lines" crossing a hypertrophic spur or crossing an ossified longitudinal ligament (Schröder) Whether they represent actual traumatic "fracture lines," separate bones (fig 362) or "umbauzones" is not yet definitely explained (zur Verth)

Authors to be consulted Baumann, Beck, Blanke, Boos, Brandis, Burkhardt, Ellmer, Ewald, A W Fischer, Gaugele, Güntz, Häbler, Haumann, Hellmer, Hesse, Hustin, Jäger, Jentzer, Lob, Mau, Milko, Nicolas, Novak, Pels-Leusden, Plate, Ruge, Schad, Schmieden, Schrader, Segre, Steinmann, Übermuth, Waagner and others

VI. Deformities of the Spine

A. The kyphoses

1. Congenital kyphosis

Numerous malformations of the spine are associated with kyphosis which, because of static pressures resulting from progressive changes in the malformed vertebrae, may occur in the prenatal or postnatal period These changes are particularly notable when there exists nonfusion of vertebrae in the sagittal plane (figs 47—49), persistence of the notochord (figs 56 and 57), dorsal hemivertebrae (figs 51 and 52) and failure of ossification of the vertebral bodies These malformations have been described in detail in chapter II

2. Juvenile kyphosis

Juvenile kyphosis occupies a considerable place in the literature, and Scheuermann was the first to call attention to this deformity He demonstrated that in a lateral radiograph the anterior stature of the vertebral bodies was less than their posterior stature, and that they were cuneiform in shape He noted, too, that early in the process there were irregular contours at the level of the vertebral rims (his term was "vertebral epiphyses") and at the level of the vertebral plates which he thought to represent growth disturbance of the bone Since Scheuermann had had no opportunity to carry out anatomic studies, he based his conclusions on the study of radiographic material and connected juvenile kyphosis with the osteochondritis dessicans described by Perthes and Calvé Mau, who made an extensive study of juvenile kyphosis, was of the same opinion and believed the kyphosis to result from necrosis of the "vertebral epiphyses" which he had induced, experimentally, in the tails of rats The radiographic findings described by Scheuermann were confirmed by numerous other writers (Edelstein, Harrenstein, Hanson, Kohle, Mau and others), but the etiology and the pathologic anatomy of these changes remain controversial The pertinent questions are Is the vertebral rim involved, and to what extent? Is the involvement the actual cause of the kyphosis? In the French literature the disease is known as "vertebral epiphysitis" and the pain which occurs in the initial phase of the disease is emphasized ("painful vertebral epiphysitis", Delahaye, Gourdon, Mayer, Mocquot and Baumann, Rocher and Roudil and others) Eckhardt called the disease "osteochondritis deformans juvenilis dorsi" v d Osten-Sacken considers disturbance of enchondral ossification to be the prime etiologic factor, but Donati believes an alteration in the process of calcification to be responsible for juvenile kyphosis Many other causes have been suggested subacute osteomyelitis (Mocquot and Baumann), tuberculosis (Freyka), discrepancy in the rate of growth of the sternum and the spine (Mutschlechner), etc

Following the publication of Schmorl's description of fibrocartilaginous nodes *(Schmorl's nodes)* W Muller and Harrenstein noticed the frequency of the occurrence of such nodes in spines showing juvenile kyphosis Subsequent personal investigation carried out by Schmorl served to throw light on the relationship of these fibrocartilaginous nodes and juvenile kyphosis Scheuermann's disease develops in juveniles who exhibit congenital expansion of the discs in the region of the nucleus pulposus (figs 368, 369 and 375) Where these expansions occur, there is thinning of the cartilaginous plates and associated decreased tensile strength When such spines are submitted to excessive stress, such as hard labor or strenuous exercises during the growth period, the thin cartilaginous plates may rupture and disc tissue may prolapse into the cancellous bone of the vertebral body (figs 370—373) Sometimes, the rupture of the cartilaginous plate extends to the periphery of the plate (fig. 376) The presence of depressions in the superior and inferior vertebral plates in juvenile kyphosis led Lindemann to postulate that the disease is a form of "dysostosis enchondralis" Laederer attached great importance to the microscopic foci of necrosis found in these cartilaginous plates and referred to them as "abortive centers of ossification" It is probable that they represent the

perforations in the cartilaginous plates described by Schmorl (cribriform plates, p 13) Laederer has found that prolapse of disc tissue through these perforations results in the formation of Schmorl's nodes more often than prolapse through the remaining vascular channels, since vascular regression is of later occurrence, this is in accord with the results of Schmorl's investigations This disc tissue prolapse, aggravated daily by the excessive stresses imposed on the vertebrae, leads to loss of the elasticity and the mobility of the discs At the same time, the growth zone found opposite to the disc on the vertebral body surface, consisting at this age of hyaline cartilage, is subject to considerable destruction (figs 22 and 23) The loss of elasticity of the disc and the subsequent diminution in the volume of disc material results in a closer approach of the vertebral bodies to each other This is true, especially, in the anterior portion of the space since posteriorly the small vertebral joints prevent the mutual vertebral body approximation Thus the intervertebral space becomes cuneiform with the apex of the wedge placed anteriorly and with the stresses concentrated on the anterior portions of the vertebral bodies Since this entire process occurs during the growth

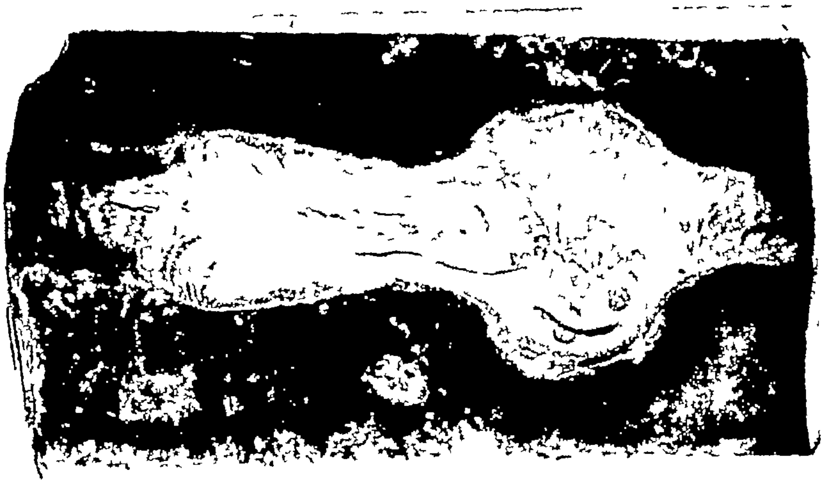


Fig 368 Slightly enlarged photograph of a sagittal section of a thoracic intervertebral disc Expansion of the nucleus and disorganization of the fibers of the annulus fibrosus (see figs 59 and 60)

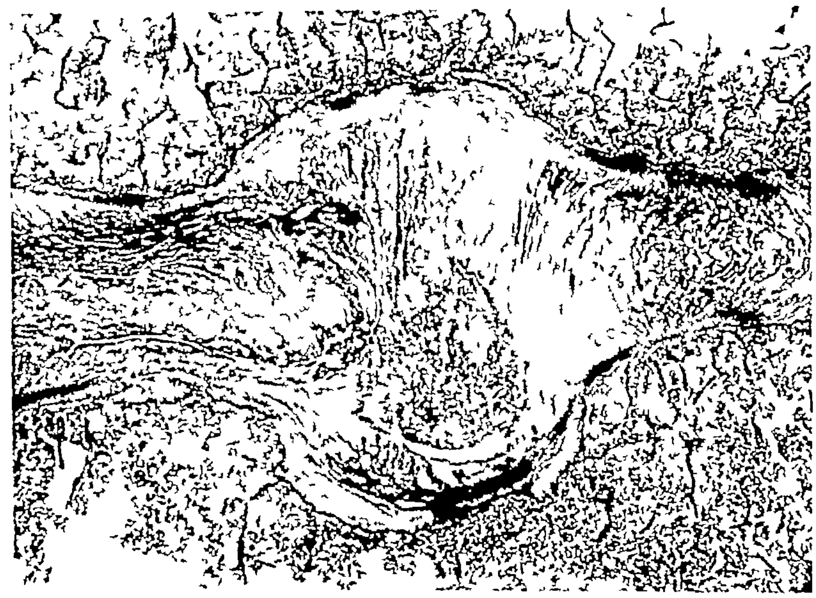
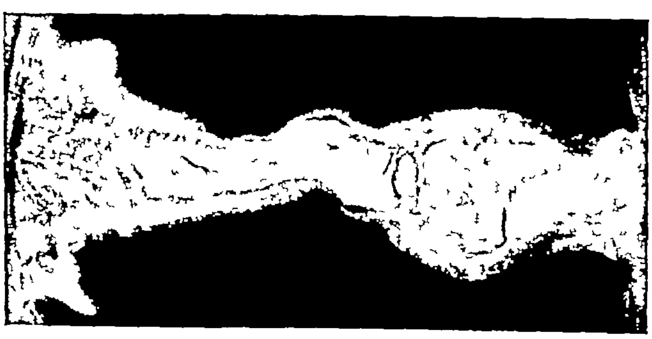


Fig 369 The central portion of the section seen in figure 368, considerably enlarged Changes in the structure of the nucleus pulposus and the vertebral plates are clearly shown In the lower vertebral plate, slightly to the left, the formation of a bony shell is beginning



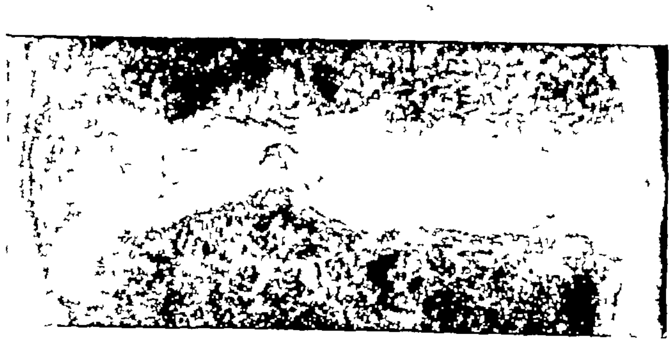


Fig 370 (left) Photograph of a sagittal section of a thoracic disc of a 17 year old boy with juvenile kyphosis Expansion of the nucleus pulposus upward and downward with flattening of the central portion of the disc Interruption of the cartilaginous plates (x—x) On the left the cartilaginous vertebral rims of the adjacent vertebrae are shown The lower rim shows beginning ossification

Fig 371 (right) Photograph of another section from the same specimen (fig 370) Numerous ruptures of the cartilaginous plates with protrusion of disc tissue into the vertebral spongiosa and reactive cartilaginous formation around these protrusions

period, the concentration of pressure results in the formation of cuneiform vertebrae with anterior flattening of the vertebral bodies (figs 380—384)

These changes are accompanied by other structural alterations in the vertebral bodies, as we have described in chapter IV B 1 Following prolapse of disc tissue into the cancellous structure of the vertebra, there forms a surrounding shell which, at first, is cartilaginous and, later, osseous

Fig 372 Photograph of a sagittal section of a disc of a man, age 38, with juvenile kyphosis Infractions of the superior and inferior cartilaginous plates with prolapse of the disc tissue Grape cluster form of the inferior prolapse The bony vertebral rim in its anterior portion (on the right in the figure) is intact

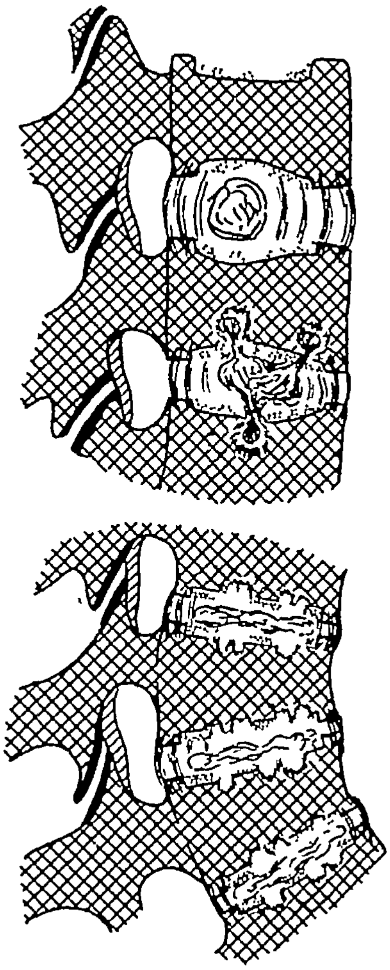


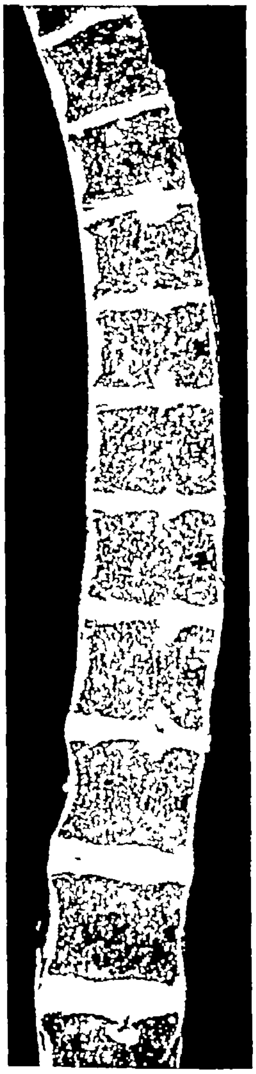
Fig 373 (left) Photograph of a sagittal section of an intervertebral disc in a case of juvenile kyphosis Multiple ruptures of the cartilaginous plates with prolapse of disc tissue into the vertebral spongiosa and with reactive cartilage formation and eburnation of the spongiosa around the prolapsed tissue The osseous vertebral rims anteriorly (on the left in the figure) are intact Fibrosclerotic changes of the disc can be seen

Fig 374 (right) Diagrammatic illustration of the development of juvenile kyphosis Frequently developmental depressions of the vertebral plates predispose to ruptures of the cartilaginous plates and to prolapse of disc tissue. As a rule the vertebral rims remain intact (figs 377 and 378)

There are also changes which occur within the disc itself Blood vessels and connective tissue extend through the fissures of the cartilaginous plate and invade the disc tissue with resultant extensive fibrotic changes and ultimate immobilization of the adjacent vertebrae (figs 373 and 383) The evolution of these processes is easily followed in a series of sagittal sections of a fresh anatomic specimen (figs 368—373, 380 and 383) The invaginations of Schmorl's nodes are easily demonstrated in macerated spines (fig 376) The changes of juvenile kyphosis usually involve the lower thoracic and the upper lumbar vertebrae and, as a rule, from six to eight neighboring vertebral discs are affected The kyphotic portion of the lower thoracic or the thoracolumbar spine exhibits a broad arch-like deformity which ultimately undergoes rigid immobilization The superior and inferior contours of the intervertebral spaces show marked irregularity and the cartilaginous plates are destroyed (fig 370) Lienert and others have also described a "lumbar" type of juvenile kyphosis limited to the upper lumbar region (fig 379)

Even at a more advanced age one can recognize juvenile kyphosis both in the sagittal section of the spine (figs 380 and 383) and radiographically (figs 381, 382 and 384) Sometimes, with advancing age, the osseous shell surrounding the fibrocartilaginous nodule may undergo absorption, and this occurs when, because of loss of elasticity of the discs and mobility of the spine, the disc ceases to transmit pressure to the prolapsed fragment Mau has confirmed this phenomenon by serial radiography In juvenile kyphosis traction and other abnormal stresses may occasion osteophyte formation on the anterior surfaces of the vertebrae but, as in senile kyphosis (p 206)

Fig 376 Photograph of the superior surfaces of two macerated thoracic vertebrae from a case of juvenile kyphosis Marked depression of the vertebral plates



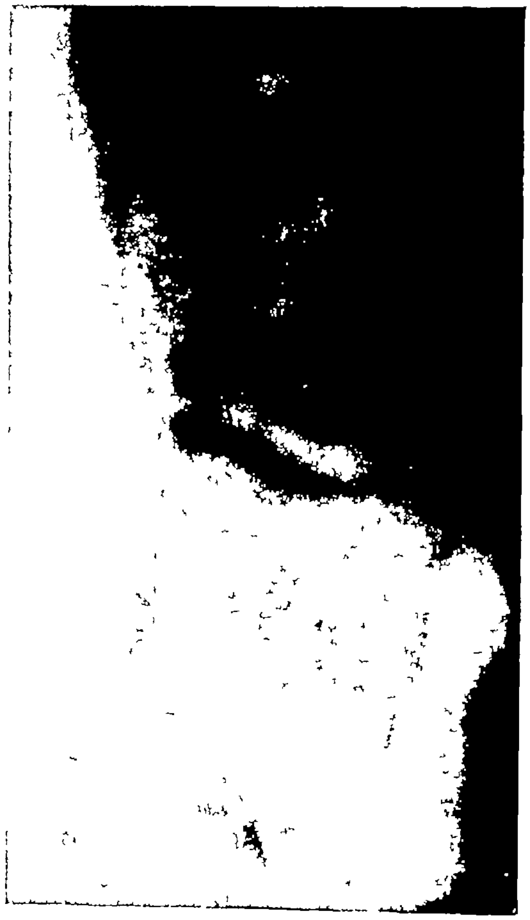
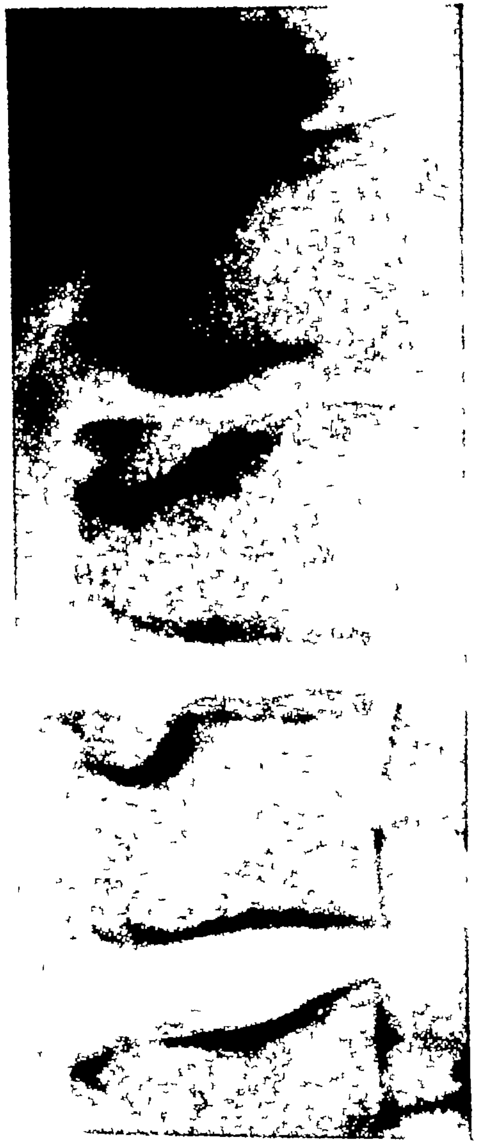


Fig 375 (left) Photograph of a sagittal section of the spine of an adolescent Numerous Schmorl's nodes, without noticeable change in the curvature

Fig 377 (center) Lateral radiograph of thoracic spine of a 16-year old boy with juvenile kyphosis Marked irregularities at the level of the vertebral plates, particularly anteriorly, typical of juvenile kyphosis Vertebral rims intact

Fig 378 (right) Planigraphic section of the case shown in figure 377 Ruptures of the vertebral plates are shown more clearly



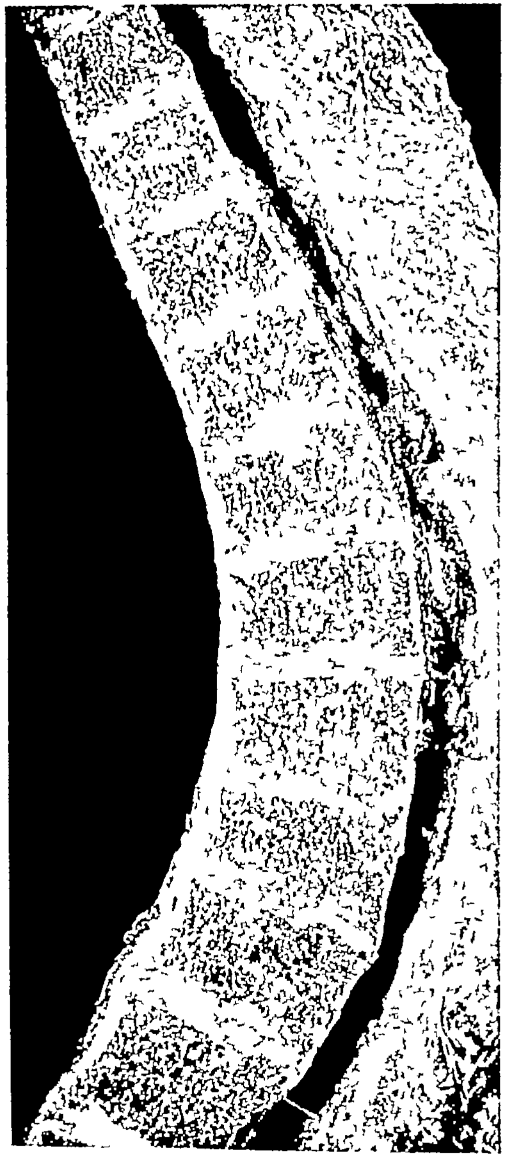


Fig 379 (left) Lateral radiograph of the lumbar spine Boy, age 17 Juvenile kyphosis involving the lumbar spine Deep protrusion of the discs into the adjacent vertebrae in the anterior portions, particularly in L 2, with disturbance in the growth of the vertebral rims — Fig 380 (center) Photograph of a sagittal section of the thoracic spine. Man, age 58 Marked kyphosis secondary to cuneiform deformity of the vertebrae resulting from juvenile kyphosis The vertebral plates of the cuneiform vertebrae show irregular contours and the presence of Schmorl's nodes — Fig 381 (right) Lateral radiograph of a sagittal section of the thoracic spine Man, age 30 Cuneiform deformity of the vertebrae with irregular plates, narrowing of the disc spaces, and Schmorl's nodes Minimal hypertrophic spurs

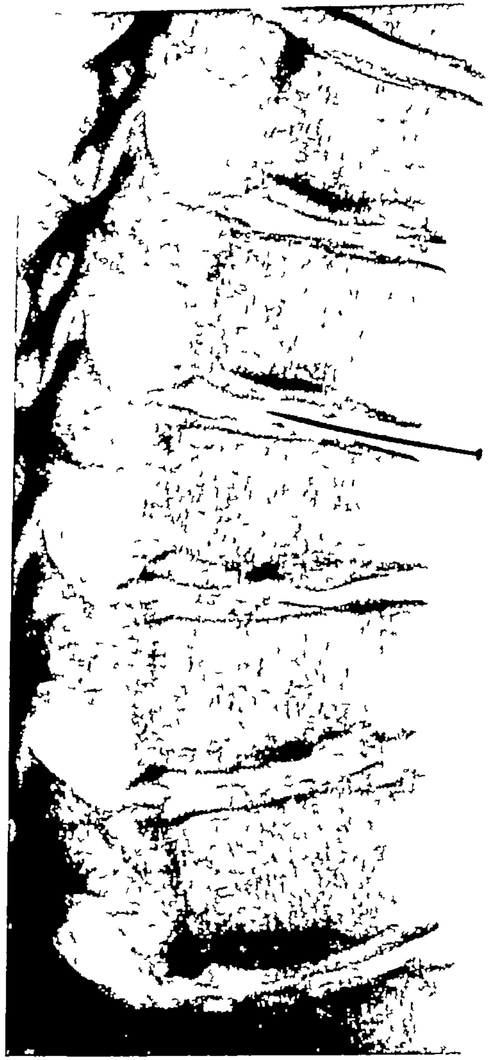


Fig 382 (left) Lateral radiograph of a sagittal section of the spine Man, age 48 Healed juvenile kyphosis Slight kyphosis resulting from cuneiform deformity of the vertebrae The intervertebral spaces are narrowed, the vertebral plates irregular, and there are Schmorl's nodes — Fig 383 (center) Photograph of a sagittal section of the spine Man, age 54 Marked kyphosis, especially in the lower thoracic region Narrowing of the disc spaces, with irregularity of the vertebral plates and degenerative changes in the discs (fibrosis, brown degeneration, vascularization) — Fig 384 (right) Radiograph of the specimen shown in figure 383 Old juvenile kyphosis Osteophytes bridge some of the vertebrae

and in spondylosis deformans (p 192) these disappear when immobilization is complete These osteophytes are demonstrable radiographically (Boerema Reissner) In a few well-advanced cases of juvenile kyphosis, Bischofsberger observed the formation of synostoses at the anterior margins of the vertebrae

As a rule, the kyphosis develops slowly and only in those who perform hard labor while in bending positions (such as carrying heavy weights) does it have a more marked and more rapid course Scheuermann believes that a single unusual effort may precipitate the onset of juvenile kyphosis It is probable that such a case reflects the presence of cartilaginous plates which are insufficient developmentally and which can rupture following a single effort beyond their capacity Such rupture favors the prolapse of quantities of disc tissue into the vertebral bodies and hastens the development of kyphosis

During the development of juvenile kyphosis, radiographs may demonstrate anomalies of the ossification of the vertebral rims (Lyon and Marum, Mau, Scheuermann and others), and this has

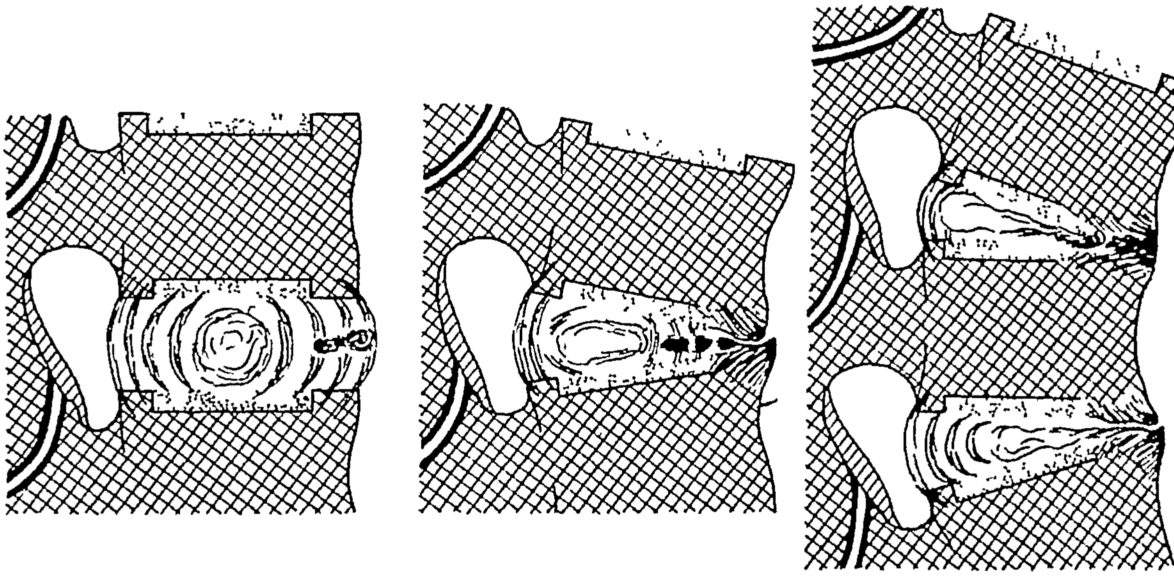


Fig 385 Diagrammatic illustration of the phases of senile kyphosis Fissuring and crushing of the disc tissue in the anterior portion is followed by narrowing of the disc in this area and subsequent friction of the anterior margins of the adjoining vertebrae with gradual eburnation and ossification (figs 388—393)

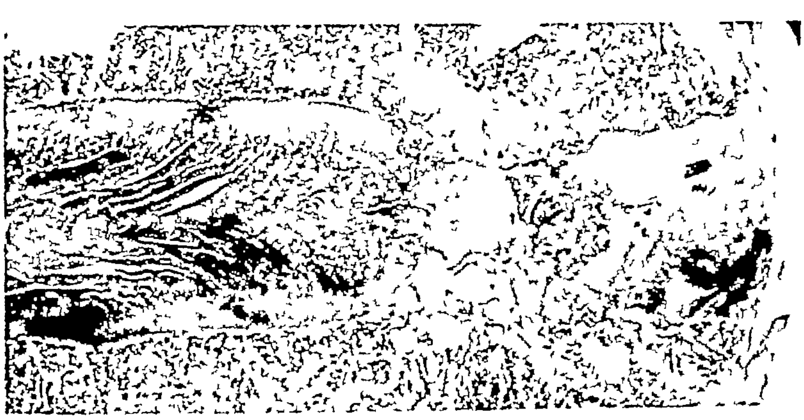


Fig 386 (right) Photograph of a horizontal section of two discs of two elderly men The upper disc shows fissuring of the nucleus pulposus and necrotic foci in the anterior portion of the annulus fibrosus *The lower disc shows* a large crescent shaped fissure paralleling the posterior margin The adjacent vertebral plate is visible through the fissure

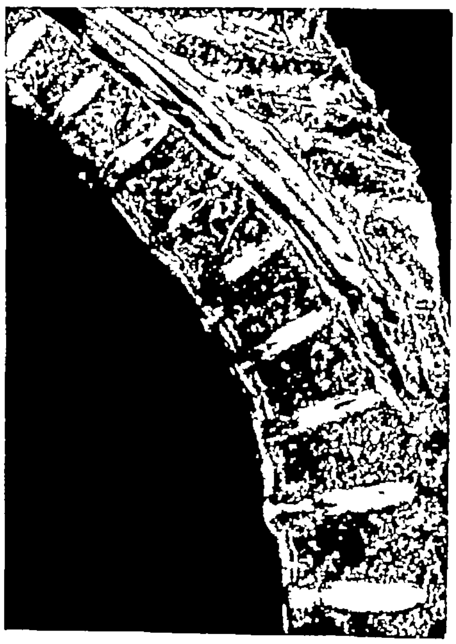
Fig 387 (left) Microphotograph of a section through the anterior portion of a disc and the adjacent vertebral plates Early phase of senile kyphosis Destruction and invasion of the anterior portion of the disc by vessels, connective tissue and bone

Fig 388 Photograph of a sagittal section of the thoracic spine of an elderly man Early senile kyphosis At the crest of the kyphotic curvature, ossification of the anterior portions of the disc is visible Eburnation of the adjacent bone Moderate marginal osteophytes

Fig 388

lead to the erroneous application of the term "epiphysitis" (p 198) It is possible that increased pressures on the anterior portions of the vertebral bodies produces wedging of the vertebrae and that this interferes with the normal ossification of the vertebral rims Schmorl found no evidence of any inflammatory process involving the vertebral rims, and radiographic study, including planigraphy, showed intact vertebral rims in patients with severe juvenile kyphosis (figs 377 and 378, Semm) In older patients, in whom healing and immobilization has occurred, the vertebral rims are always well-developed Scheuermann was of the firm opinion that the disease nearly always originated in the vertebral rims and that only rarely would Schmorl's nodes be the cause of juvenile kyphosis Since we do not have at our disposal serial histologic studies of the vertebral rim and the adjacent structures in the early stages of juvenile kyphosis, the problem is not easily solved The role of endocrine disorders (Müller), fragility of the spine (Schede), and osteoporosis (Lyon and Marum) in the production of juvenile kyphosis is unknown Wolf found a normal phosphatase level in the blood of patients with this disease and excluded rickets as a cause

Severe juvenile kyphosis may be complicated by cord damage, probably resulting from the posterior protrusion of large fibrocartilaginous nodules (p 141, Blum) Lindgreen, using myelography, demonstrated narrowing of the neural canal at the crest of the kyphosis and found widening of the peridural space above the curvature (Albanese, van Assen, Boerema, Brocher, Burdzik and Wunsch, Calvé, Charmant, Eckhardt, Eichelbaum, Grub, Hafner, Hanson, Hetzar, Ihlenfeld, Lotze, Lindemann, Manara, Marcer, Neschkes, Overgaard, Schildbach, Schlegel, Schmid, Schmidt, Schuhknecht, Stein and v Zahn, Wölfer)



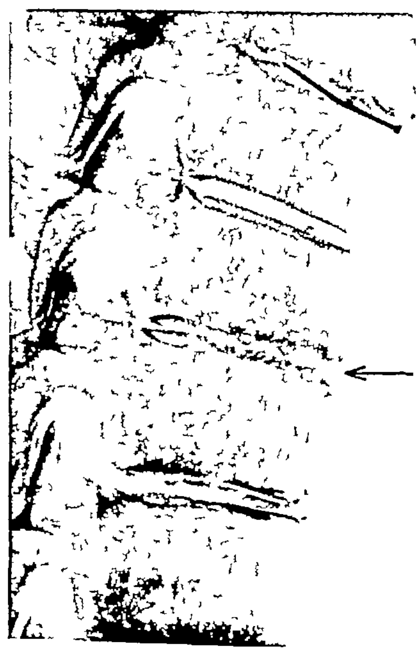


Fig 389 (left) Photograph Sagittal section of the thoracic spine Woman, age 85 Moderately developed senile kyphosis Narrowing of the discs anteriorly with some ossification

Fig 390 (right) Lateral radiograph of a sagittal section of the thoracic spine Woman, age 75 Beginning senile kyphosis Arrow indicates osseous proliferation in the disc tissue Minimal osteophytosis

3. Senile kyphosis

In contrast to the juvenile form of the disease, senile kyphosis commonly involves the midportion of the thoracic spine in the region of the normal curve Its characteristic feature is the change in the intervertebral discs, with the vertebral bodies remaining intact It is to be noted that senile kyphosis and osteoporotic kyphosis are quite different processes, although both occur in the middle portion

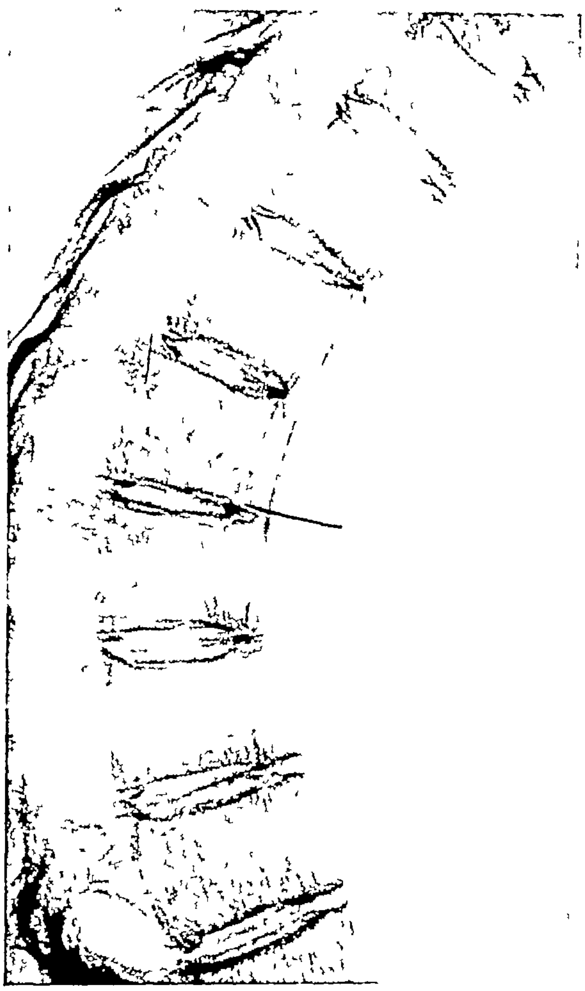


Fig 391 (left) Lateral radiograph of the thoracic spine of a 63 year old woman Beginning senile kyphosis Narrowing of the discs anteriorly with eburnation of the adjacent bone and some osseous proliferation Moderate osteophyte formation

Fig 392 (right) Lateral radiograph of a sagittal section of the thoracic spine Woman, age 85 Pin is in the T 6—T 7 disc Senile kyphosis with osseous ankylosis anteriorly

of the thoracic spine (fig 116) They are of quite different pathogenesis, the origin of osteoporotic kyphosis being the wedging of the vertebral bodies, while disc changes result in the production of senile kyphosis We have remarked earlier that, with advancing age and with atonicity of the musculoligamentous apparatus of the vertebral column, the anterior portions of the vertebral bodies and the discs of the thoracic spine are subjected to increased pressures These pressures are responsible for the wedging of the osteoporotic vertebral bodies In the absence of significant osteoporosis, the anterior disc segments are compressed by well-preserved vertebral rims with resulting degenerative changes in the involved disc (fig 386) The earliest of these changes is the concentric fissuring of the anterior portion of the disc, paralleling the inner margin of the vertebral rim (fig 387) The fissures may assume the form of clefts but, commonly, they are crescentic and are filled with blood Vessels and granulation tissue appear and, ultimately, the osteogenetic process results in the bridging of the space by bone trabeculae, which replace the involved portion of the disc The remainder of the disc is unchanged (see figs 388 and 389) The increased pressures to which the

anterior segments of the discs are submitted lead not only to fissuring, but to crushing and necrosis of these portions contained within the circumference of the vertebral rims In the anatomic specimen, the crushed disc seems dry, and appears to be dark yellow in color, and the disc space (in this area) is narrowed Necrosis of part of a disc leads to abnormal mobility of the vertebrae, accentuated by the loss of elasticity of the disc The adjacent vertebrae may be in contact with each other and friction between them may lead to eburnation (figs 388, 391 and 393) As these changes continue, the necrotic portions undergo organization, and bone formation and bridging produce the result described previously (figs 390, 392 and 393)

These changes, i e , narrowing of the anterior third of the disc space, eburnation of the vertebral plates and ossification of the anterior portion of the disc, are readily recognizable in a radiograph, as shown by Junghanns (using cadavers) and by Alajouanine and Mauric (using living subjects, figs 390—393) In the thoracic spine the disc changes progress from above downwards (figs 388 and 393) The lower discs may show only early changes (e g , decrease in height), while ossification of the disc may be complete at a higher level Thus, the magnitude of the kyphosis may increase steadily (fig 393)

The illustrations (figs 388—393) show the various stages of narrowing of the disc spaces When there is involvement of several discs in the same region of the spine, marked kyphosis may occur without wedging of the vertebral bodies, as is the case in osteoporotic kyphosis

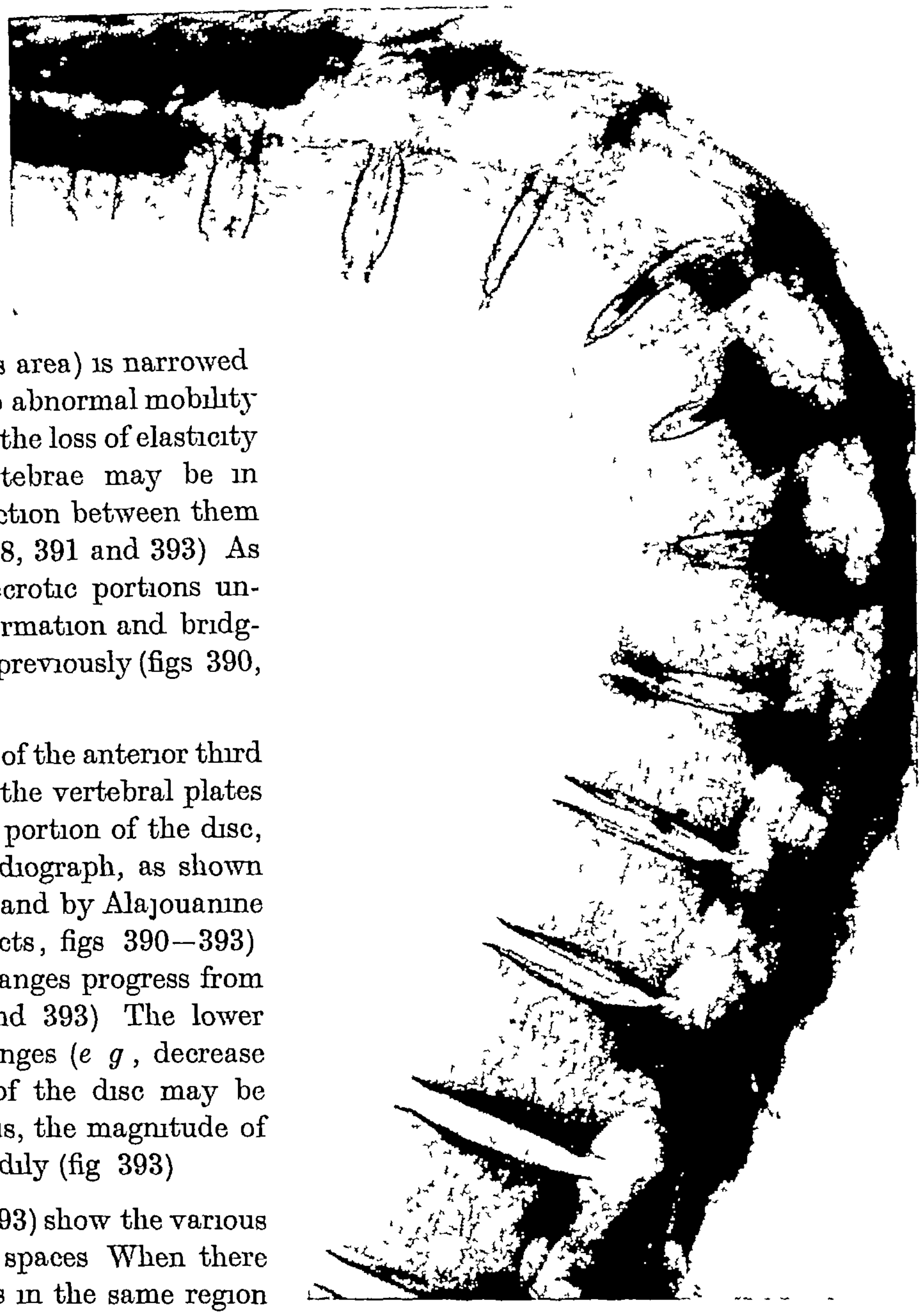


Fig 393 Lateral radiograph of a sagittal section of the thoracic spine Woman, age 67 Senile kyphosis with osseous ankylosis of several vertebrae in their anterior portions One intervertebral disc below narrowed anteriorly with eburnation of the adjacent bone

Although senile kyphosis may be seen in relatively young patients (in the fifth decade), it is encountered, as a rule, only in much older persons It has nothing in common with juvenile kyphosis which, clinically, radiologically and anatomically, is a quite different disease The difference between them is so definite that anatomic or radiologic recognition of the superimposition of senile kyphosis on a pre-existing juvenile kyphosis is quite possible Senile kyphosis, moreover, commonly involves the midthoracic region, while juvenile kyphosis affects the lower thoracic spine or the thoracolumbar region

Ossification of the anterior portions of the discs results in complete immobilization of the involved segment of the spine and represents the final stage of the disease Following this immobilization, eburnation disappears, the osteophytes are absorbed and the anterior surface of the vertebral column becomes quite smooth (figs 392 and 393) Finally, ossification of the anterior longitudinal ligament occurs, bone trabeculae bridge the anterior margins of the adjacent vertebrae, and the spine adapts itself to new static conditions

Fig 394 (left) Lateral radiograph of a sagittal section of the thoracic spine Woman, age 83 Combination of senile and osteoporotic kyphosis In the upper segment there is typical senile kyphosis with osseous ankylosis Wedging and biconcave deformity of the vertebrae due to osteoporosis in the lower region

Fig 395 (right) Photograph of the macerated thoracic spine Woman, age 68 Senile kyphosis with ossification of the anterior portions of some of the discs Osteophytes are less marked in the nonankylotic region

Although the ankylosis of senile kyphosis is somewhat similar to that of ankylosing spondylarthritis (chapter VII B 2), it is difficult to confuse these two conditions One needs only to observe the small vertebral joints In senile kyphosis they remain intact, but in ankylosing spondylarthritis they are solidly fused

The forms of senile kyphosis which we have described have nothing in common with spondylosis deformans In the latter the osteophytes, which may bridge adjacent vertebrae, arise from the anterior surfaces of the vertebrae and have an appearance quite different from those seen in senile kyphosis These differences are apparent both anatomically and radiographically

Senile kyphosis is to be considered as typical only when there is no element of osteoporosis present, since the osteoporotic wedging of the vertebral bodies is sufficient in itself to produce a kyphosis Persons of advanced age may, sometimes, present a combination (fig 394) of osteoporotic and senile kyphosis and, in such cases, one must assume that the osteoporotic process was secondary to the senile kyphosis A typical case is shown in figure 394, with the typical changes of senile kyphosis (ossification of the anterior portions of the discs) and with the compressed, cuneiform vertebrae

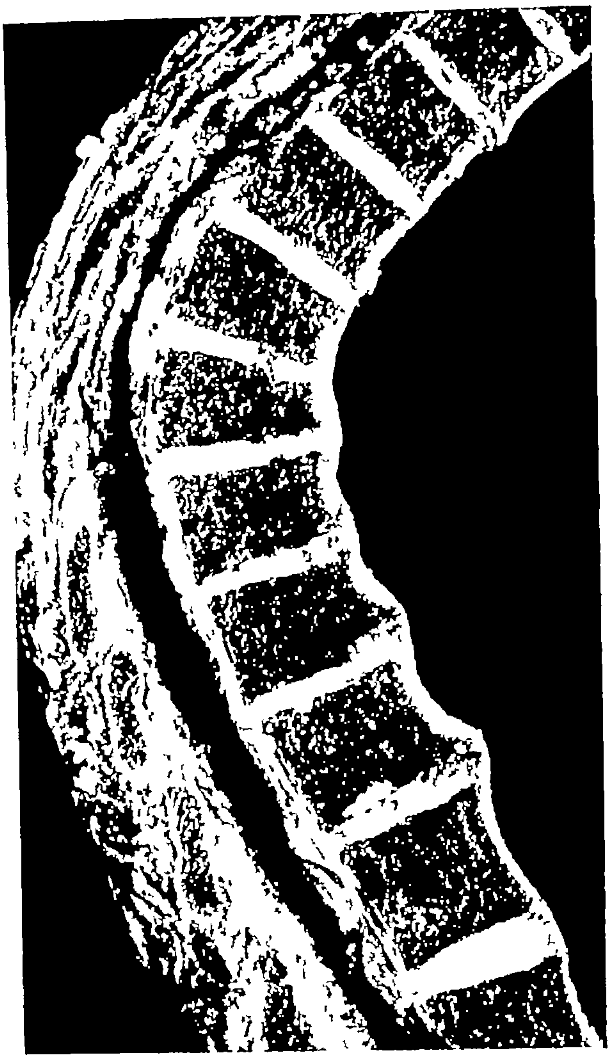


Fig 396 (left) Photograph of a sagittal section of the spine Man, age 49 Angulation of the midthoracic region resulting from old compression fractures Ossification islands are present in several discs

Fig 397 (right) Radiograph of the specimen shown in figure 396 Marked anterior compression of T 10 with post-traumatic sclerosis

of osteoporosis in the lower thoracic spine It is interesting to note that the upper segments of the thoracic column, which are bridged by the ossified discs, retain their shape in spite of the osteoporosis This suggests that the anterior ankylosing process made these vertebrae less likely to collapse and shifted the stresses to a lower portion of the thoracic spine

4. Kyphosis resulting from trauma, infection, or neoplasm

The post-traumatic deformities of the spine are usually angular and rarely assume the arching curve of the other kyphoses The differentiation between post-traumatic kyphosis and that due to infectious disease is difficult, since both have identical forms (Blümel)

The rarely seen arching curve which may follow trauma is much like the curvature of juvenile or senile kyphosis, and differentiation by radiography alone is impossible In the Institute of Dresden we examined the skeleton of a soldier (age 36) who, some twelve years before, had been buried by the cave-in of a dugout and who had remained in a position of forced flexion for a considerable period of time (figs 396 and 397) Following his extrication from the cave-in, he underwent bed rest for a long period and finally exhibited a marked arching kyphosis of his thoracic spine which, prior to the accident, had been quite normal Without the past history, the evaluation of the skeletal deformity would have been impossible The specimen (fig 396) showed an arched kyphosis of the middle and lower thoracic spine with cuneiform vertebrae and with anterior ossification of

the discs which, it seems likely, had been crushed The disc ossification and the irregularity of the anterior portions of the vertebral plates is readily recognizable in the radiograph (fig 397) Since there were no Schmorl's nodes, the diagnosis of juvenile kyphosis seems untenable

It is not uncommon for fractures of two widely separated vertebrae to occur, resulting in the presence of two separate kyphoses In such a case, the spine between the two fractured vertebrae appears to be unusually straight (figs 402 and 403) A permanent kyphosis may follow fractures or fracture dislocations (fig 167)

Kyphosis following infectious spondylitis (chapter III I) is usually seen as a sharp angulation (gibbus deformity), reflecting the collapse of vertebral bodies and destruction of the discs by the infectious process (fig 346) After healing, a "block vertebra" is formed at the crest of the curvature (fig 189)

Malignant disease of the spine may produce either angulation or an arching kyphotic curve (figs 201, 208 and 209) Myeloma is a common etiologic factor, and a large hemangioma may result in the collapse of a vertebral body (Bailey and Bucy, Junghanns, Makrycostas and others) With osteolytic metastatic involvement, the kyphosis usually develops rather gradually, but intervening trauma may precipitate sudden vertebral collapse, sometimes with section of the cord and paralysis When isolated segments of the spine exhibit kyphosis secondary to metastatic disease, the uninvolved segments appear to be unusually straight, as is seen with multiple fractures Cord tumors, occurring during the growth period, may affect the growth of the vertebrae, resulting in a deformity of the spine (Olsen)

5. Other kyphoses

Any generalized bone disease of the vertebrae with decreased strength of the lamellae (osteoporosis, the deficiency states, the osteodystrophies) may result in the occurrence of kyphosis As a rule, the deformity consists of accentuation of the physiologic kyphosis of the thoracic spine and reflects the presence of cuneiform vertebrae There is, however, a series of kyphoses which are associated with numerous diseases, the etiology and the anatomic features of which are not well understood Frequently, these kyphoses are regarded as incidental findings, and, certainly, they require further investigation In particular, we need to know whether they may be included in the classification of the known kyphoses, or must be regarded as separate entities

Mutschlechner has described kyphosis occurring in various diseases He considered acromegalic kyphosis and that of eunochoid gigantism (Koch, Wagenseil) to be due to excessive growth of the vertebral bodies in contrast to the normal growth of the sternum W Muller, however, believes this form of kyphosis to be a variant of the juvenile form (Schmorl's nodes, etc), and Albanese is in agreement with him Kyphosis is frequently seen in myopic or in asthenic individuals, in Friedreich's disease, and in syringomyelia (Mutschlechner), and those with epidemic encephalitis nearly always exhibit a kyphotic posture

Ankylosing spondylarthritis is characterized by an arching kyphosis of the entire spine (chapter VII B 2), but the mechanism of this kyphosis is not entirely clear It is possible that it represents an effort to spare the inflamed small joints from stress, and that the ankylosis becomes fixed with the arrest of the inflammatory process

Michaelis finds neurofibromatosis (Recklinghausen's disease) to be associated with spinal deformity, which he describes as "kyphosis with a mild scoliosis" and Jentschura, in a well-documented article, agrees with this observation Jentschura lays especial stress on the occurrence of scoliosis, and believes the etiologic factor to be multiglandular endocrine disorders and hereditary deficiency of the mesodermal anlage

Haas was able to produce scoliosis and kyphosis experimentally by irritation of the proliferation cells of the cartilaginous plates He was successful, also, in preventing the occurrence of such deformities by fusion of the spinous processes, using a bone graft Additional experimental work combined with adequate histologic studies may give us a better understanding of the mechanisms involved

B. The lordoses

The physiologic lordoses of the cervical and the lumbar spine may be subject to pathologic modifications capable of alterations in the statics of the spine and of provoking important anatomic changes

A normal lordotic curve may be increased as compensation for a kyphosis When, during the growth period, an angulation develops in the thoracic spine (*e g* , as in tuberculosis) there follows a compensatory increase in the vertical diameters of the lumbar vertebrae (fig 189) and this produces an exaggerated lordosis (Benassi, W Muller) According to Mutschlechner, marked lumbar lordosis is frequent in chondrodystrophy and progressive muscular atrophy Lordosis may, occasionally, result from cleavage of the spinous processes (Feller and Sternberg) Marked increase in the cervical lordosis may result in compression of the esophagus (Knopflach) Wilde has described a special form of lumbar lordosis (fixed lordosis) of infectious origin

When the lordosis is markedly accentuated, the spinous processes may come in contact with each other Thus, pseudoarticulations are formed and these are subject to degenerative changes with osteophyte formation (Baastrup's disease)

Spondylolisthesis is accompanied by flattening of the normal lumbar lordosis (see Chapter VI D) and by tilting of the pelvis Flattening of the lumbar lordosis is also seen with retrolisthesis * Complete straightening of the lumbar spine (complete flattening of the lumbar lordosis) is indicative of intervertebral disc damage It occurs, also, with a variety of conditions, such as, intervertebral osteochondrosis, posterior disc prolapse, block vertebra, infectious processes, etc Its presence demands a search for radiologic signs of a disc lesion or for osseous changes Alterations of the lordotic curve are seen regularly after laminectomy

C. The scolioses

Lateral curvatures of the spine (the scolioses) are considered to be the most common deformities encountered This opinion, based on clinical statistics, does not take into consideration, we think, the fact that scoliosis (common in young adults and juveniles) is a frequent stimulus to medical consultation, while kyphosis is regarded as a common phenomenon of the aging process Our studies indicate that scoliosis is a much less common spinal deviation than kyphosis The anatomic study of scoliosis is made difficult by the presence of associated rotation of the vertebrae and a frequent concomitant kyphosis (kyphoscoliosis) The large number of publications which discuss this subject is an index to the complexity of the problem It may be mentioned that the original purpose of the careful and systematic examinations of the spine, which Schmorl instituted, was the clarification of the problem of scoliosis If, in the course of these extensive investigations, including the study of some 10,000 spines, other problems of the normal and pathologic spine were solved, the solution was only one facet of a study directed at scoliosis It must be conceded, however, that a satisfactory solution of the problem of scoliosis has not been found

1. Congenital scoliosis

The role of a congenital hemivertebra in the production of scoliosis was known to the ancients (Rokitansky) Scoliosis with various congenital malformations (hemivertebra, hemimetameric segmental displacement, etc) was discussed in chapter II Depending on the location of the malformation, scoliosis may involve any region of the spine (figs 50, 103—108) Faber has studied the relationship of heredity to scoliosis

2. Acquired scoliosis

Although, according to our observations, kyphosis is of much more frequent occurrence than scoliosis, the latter is the subject of a vast clinical literature This, no doubt, is because scoliosis not

* A term used to indicate a posterior vertebral displacement, frequently described as "reverse spondylolisthesis" (ed)

only causes pain, but is a phenomenon easily observed, and one that produces a marked postural alteration The consideration of the numerous hypotheses as to the pathogenesis of scoliosis is beyond the scope of this monograph, and the reader is referred to the literature Among the more recent theories are the discrepancy in the growth rate of the bodies and the arches (Heuer), and the increased water-uptake of the nucleus pulposus making the length of the body-disc series greater than that of the arches (Erlacher)

Pathologic alteration of the vertebral bodies (*e g* , lateral wedging with rotation) is among the causes of

Fig 398 (left) Photograph of the macerated thoracic spine Woman, age 63 Slight levoscoliosis with flattening of some of the vertebrae on the right side Moderate osteophytosis

Fig 399 (right) Photograph of the macerated thoracic spine of an elderly man Slight scoliosis with the convexity to the right Marked osteophyte formation on the concave side Compensatory scoliosis in the lumbar region with a few osteophytes on the concave side

scoliosis The discs show only secondary changes, with thinning on the concave side of the curve, and with displacement of the nucleus pulposus toward the convex side The discs appear to show no very striking changes, microscopic or macroscopic, in early juvenile scoliosis The vertebral rims are almost always of normal height and width, and only rarely are there seen insignificant changes resembling those sometimes observed with osteoporosis Although we lack detailed serial studies, it seems safe to say that changes in the vertebral rims are not the etiologic factors which produce idiopathic scoliosis.

Lindemann (and also Roederer and d'Intignano) believes that it results from the factors which Schmorl has described as a cause of juvenile scoliosis The control series studied by Schmorl, however, did not confirm this opinion, and additional studies are necessary

In addition to the scolioses which result from changes in the vertebral bodies, we have observed cases of scoliosis with changes in the discs on the side facing the concavity These changes resemble closely those seen in anterior portions of the discs of persons with senile kyphosis (p 206, fig 385—390) The lateral portions of these discs exhibited, on the concave aspect of the curvature, signs of degeneration, necrosis, fibrous tissue formation and eburnation of the adjacent bone Whether the disc changes are secondary to the scoliosis, or result from continued bad posture permitted by an insufficient musculature, remains a moot question (see p 133) The occurrence of juvenile scoliosis (Hauser, Lange), or "apprentice's scoliosis" (Schanz) resulting from the habitual carrying of heavy objects on one side of the body tends to support the theory of disc damage (cf scoliosis in amputees p 197)

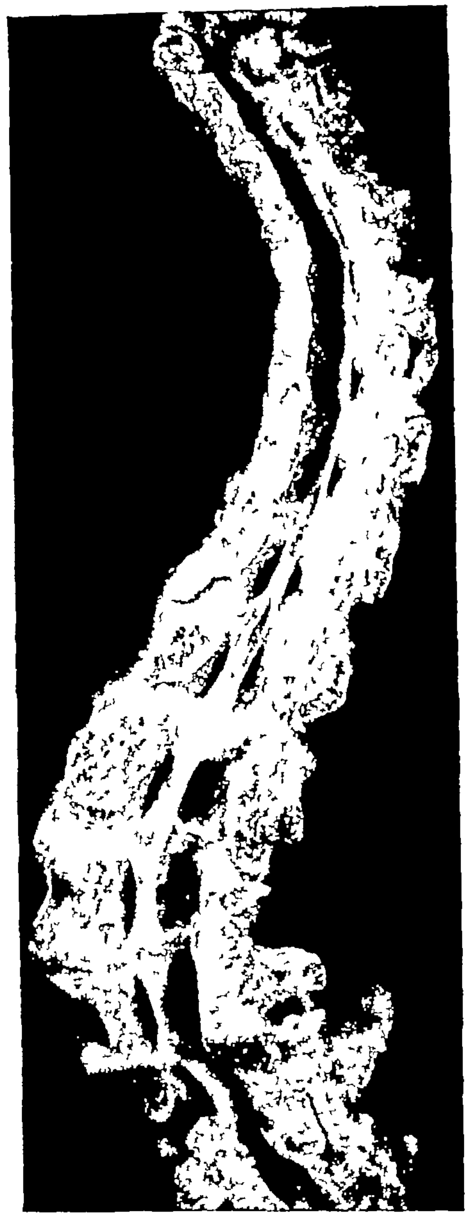


Fig 400 (left) Photograph of the macerated lumbar spine Man, age 79 Several cuneiform vertebrae fused by osteophytes on their concave side

Fig 401 (right) Photograph of the spine of an elderly man Anterior view of the neural arches after removal of the vertebral bodies The posterior longitudinal ligament follows the curvature

Reske believes the paravertebral shadow (seen in a radiograph) on the concave side of the scoliosis to be of etiologic significance and that it represents an inflammatory process in the pleura Postural scoliosis, occurring as a guarding mechanism when pain is present, might well interfere with the process of bone growth and, finally, might result in a permanent scoliosis He presents the results of his anatomic investigations in support of his opinion

A frequent and anatomically well-defined entity is the "scoliotic lumbosacral arthrosis" described by Kienböck It is a low lumbar scoliosis with the L 5—S 1 disc markedly crushed on the side of the concavity and with eburnation of the adjacent bone structures These changes are associated with clinical symptoms The changes in the L 5—S 1 disc are the result, rather than the cause, of the deformity (see pp 133, 188, 197)

Various conditions which may be factors in the production of scoliosis include muscular contractures (Johow, Mouchet), paralysis (M Lange), unilateral paralysis of the diaphragm (Harrenstein), paravertebral tumors (Frosch), sciatic pain (Strumpell), flat feet (Rotenberg and Ryvlin), fibrosis of the pleura (Roshioka), scars on the chest wall and costal synostoses (Gruca and Weisflog), thoracotomy and unilateral fusion of the spines of juveniles with interference with bone growth (Meiss) Moser produced scoliosis in animals by destruction of the zones of proliferation on one side of the vertebrae Neurofibromatosis has been found to be associated with very marked scoliosis (Jentschura, Rutt, Vigano, etc on p 244) Blumensaat and Nestmann found renal disease to be an etiologic factor in the production of scoliosis, and Blumensaat was able to produce it in experimental animals Giraudi, however, believes the relationship of renal disease and scoliosis to be a fortuitous one Zanetti is of the opinion that gallbladder disease may produce a right scoliosis by a reflex guarding mechanism For all of these scolioses anatomic evidence is lacking Lateral vertebral displacement may occur in scoliosis, but this rather uncommon finding and the displacement is not, usually, very pronounced (fig 418, p 229)

As shown in figures 398—400, osteophyte formation and subsequent "lipping" occurs, invariably, on the concave side of the scoliosis, and results, undoubtedly, from disc changes Osteophyte formation progresses as long as there is any mobility of the affected segment, but when bridging of the disc spaces has occurred and rigidity has developed, the osteophytes undergo absorption and the ankylosed area presents a smooth appearance (fig 400) Scoliosis is never a simple lateral curve but has a constant element of rotation which may be appreciated by observation of the position of the posterior longitudinal ligament (fig 401)

There have been numerous observations as to the relation of scoliosis to cord compression, and the clinical and anatomic findings have been described by Valentin and Putschar (Grobielsky, M Lange, Langenskiold, Roger and Schachter, Siebner, Wreden et al) All of the very marked scolioses are associated with decreased cardiac efficiency leading, perhaps, to a diminished blood supply to the cord in the region of the deformity, and to paralysis (Becker and Hess) For the etiology, the pathology and the treatment of scoliosis the reader is referred to the recent literature (Felix, Fenker, Fevre, Frey, Gaugele, Herbert, Hohmann, Hyndman, James, J Muller, Lackum and Smith, F Lange, Laurence and Masse, Mol, dal Monte and Teodorani, Peabody, Pizziolo, Rintelen, Schede, Schmidt, Vogel, Wiese, Wiles, Wilhelm and others)

D. Abnormal straightening of the spinal curve

In addition to the deformities heretofore described, one may see, from time to time, an abnormal straightening of a normal curvature of the spine This straightening occurs, usually, in the other sections of the spinal column It may be demonstrated only in a lateral radiograph with the subject in the upright position A segment which has been straightened by a fibrosclerotic ankylosis sometimes may be recognized in a spine removed at autopsy The frequently encountered straightening of a long segment of the spine above a crushed disc is to be regarded as a compensatory mechanism tending to prevent the displacement of a vertebral body (Güntz, cf chapter VI B) With posterior vertebral displacement, there is usually straightening of a segment of the spine above the displacement (Junghanns) True spondylolisthesis is accompanied by tilting of the pelvis and flattening of the normal lumbar lordosis, and flattening is also seen when there are large Schmorl's nodes present Pain is a common symptom In instances of widely separated multiple vertebral fractures, straightening of the intervening segments is frequent, and this is also true when inflammatory disease e g , tuberculosis, involves several noncontiguous vertebrae (figs 402 and 403) It is significant that pain is regularly associated with straightening of the normal spinal curvatures Alterations in them have not been investigated sufficiently, and they should receive more attention from both clinicians and radiologists

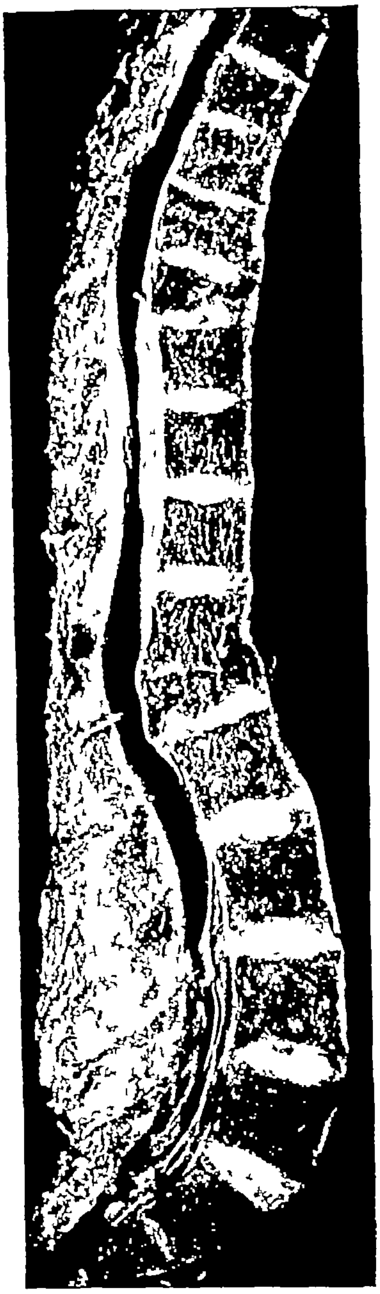


Fig 402 (left) Photograph of a sagittal section of the spine Woman, age 53 Old compression fractures of T 8 and L 1 with callus formation Marked straightening of the segment of the spine between the fractured vertebrae, while the spine above and below the fractures shows slight angulation

Fig 403 (right) Radiograph of the specimen from the previous figure Disc adjacent to fractured vertebrae shows ossification

E. The lumbosacral angle

1. The angle of the promontory and the lumbosacral angle

The lumbosacral angle has been the subject of numerous studies, and variations in it have been considered as being responsible for low-back pain The textbooks and various recent publications ascribe varying values to the "normal" lumbosacral angle and the confusion which has resulted appears to stem from the terminology employed (fig 404) Let us state definitely, therefore, our method of determining these angles There are two methods by which one may measure the angles (1) by calculating the angle formed by a straight line tangential to the anterior surface of L 5 and

its intersection with a straight line tangential to the anterior surface of S 1 (in Figure 404 this angle is formed by lines DE and EF) and (2) by calculation of the angle formed by the intersection of the vertical axis of L 5 (AB) and the vertical axis of S 1 (BC) For clarity, angle DEF will be called "the angle of the promontory and angle ABC the "lumbosacral angle" (Junghanns) The literature contains numerous references to the angle of the promontory and various values are assigned to it

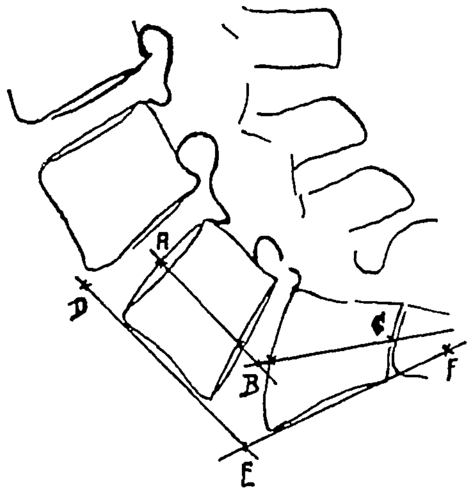


Fig 404 Tracing of the lumbosacral region ABC — lumbo sacral angle, DEF — angle of the promontory

These may be stated thus

Braus	120 to 135 degrees
Humphry	120 degrees
Chapry	108 degrees (persons of middle age)
Chapry	98 degrees (the aged)
Rauber-Kopsch	90 degrees (textbook of anatomy)

The measurement of the lumbosacral angle is a quite recent practice among radiologists Robinson and Grimm (employing radiographic measurements) found values between 128 and 160 degrees Measuring 40 anatomic specimens, they found values of from 132 to 168 degrees, an average of 155 degrees They found that a patient with a lumbosacral angle of less than 145 degrees was likely to complain of low-back pain, although they observed patients with angles of from 103 to 135 degrees who were symptom-free Wynen found an average value of 135 degrees with upper and lower limits of 115 and 160 degrees Since Wynen measured the lumbosacral angle, while Braus measured the angle of the promontory, the fact that they found identical values is probably without significance

In the literature numerous other angles are described and since all of these are called "lumbosacral angles," a considerable degree of confusion has occurred Whitman considers the lumbosacral angle to be the angle between a horizontal plane and the surface of the sacrum, and Lackum measures the angle formed by the intersection of the midline of the sacrum (seen laterally) and a vertical line Hellner, deploring this confusion, joins with Meyer-Burgdorff in accepting our definitions as being simple and as offering the best opportunities for comparison

To relate anatomic measurements to those made clinically, a large series of measurements were made in the Institute of Dresden and these have been reported by Junghanns To establish a valid mean, the measurements were carried out on adolescents, and a comparison between these, and those of adults (persons over 25 years old) disclosed no significant differences (table 9) Goniometric study of the promontory in the fetus has been made by Ciulla

2. Individual differences in the lumbosacral angle and their causes

The spine consists of multiple components each of which may contribute to the variability of the lumbosacral angle In general, the shape of the vertebral body has a marked influence on the lumbosacral angulation An example is the fifth lumbar vertebra seen laterally, where it becomes clear that it is not rectangular but slightly cuneiform

The intervertebral discs influence the angulation even more than do the vertebral bodies The thickness of any given disc may vary considerably from person to person, and it is difficult to determine an exact value The measurements made on our anatomic material showed that the anterior portion of a fresh disc of L 5—S 1 of an adolescent was about 6 mm thicker than the posterior portion and, in an adult, the difference was 7 mm

The angle formed by the opposing surfaces of S 1 and L 5 (disc angle measured on radiographs) was found to be between 10 and 27 degrees (average 17 degrees) in adolescents, and between 0 and 29 degrees (average 16 degrees) in adults Wynen found this angle to vary between 10 and 40 degrees, while J M Berry measured it at an average of 10 degrees

Table 9

Average values of the lumbosacral angle and the angle of the promontory in 155 studied cases
(Extreme values are in parenthesis)

1	2	3	4	5
Angle Age	Men		Women	
	below 25	above 25	below 25	above 25
	Angle in degrees			
Lumbosacral angle	130 (121—150)	129 (112—151)	130 (115—153)	130 (115—156)
	129 (112—151)		130 (115—156)	
	129 (112—156)			
Angle of the promontory	140 (130—156)	143 (123—157)	142 (129—155)	146 (124—164)
	142 (123—157)		144 (124—164)	
	143 (123—164)			

The thickness of the disc L 5 depends essentially on its anatomic structure We found this disc to be a normal and elastic structure in individuals of twenty-five and into the late thirties, and, on occasion, in persons of advanced age In general, however, beyond the age of 40, the discs begin to exhibit more or less significant changes consisting (as described previously) of brown degeneration, fibrous and osseous metaplasia, fibrillation, vascularization, calcification, biconvex configuration and prolapse The disc L 5—S 1, lying between a mobile vertebra and one in a fixed position, is especially subject to stress and usually exhibits the most marked changes Nevertheless, degenerative changes do not affect, significantly, the angles of the lumbosacral regions of adolescents or of older persons, and the difference between the upper and the lower limits is only a few degrees greater in the adult than in the adolescent No significant differences between the sexes have been noted (Table 9) The comparison of the values stated in table 9 with those of other writers, indicates that the lumbosacral angle has relatively constant values Our average value of 143 degrees corresponds closely to that calculated by Robinson and Grimm (155 degrees) and by Wynen (135 degrees) There are quite marked differences noted when the angle of the promontory is measured Our figure of 129 degrees may be contrasted with that of Rauber-Kopsch (90 degrees), Chapry (108 degrees), and Humphry (120 degrees) The measurements of Fick and Braus are in close agreement with ours From these figures it appears that there is a difference of 14 degrees between the lumbosacral angle and the angle of the promontory

3. Back pain and variations in the lumbosacral angle

The observations which relate back pain and variations in the lumbosacral angleare of considerable interest As mentioned previously, Robinson and Grimm consider an abnormal lumbosacral angle as a factor in the production of low-back pain Brailsford agrees with this, and believes the pain to result from traumatic rupture of the lumbosacral ligaments He quotes Herndon, who studied 498 cases of back pain and found 68 of them to have small lumbosacral angles and to have had "sprains" Goldthwait divides persons with back pain into two groups In the first group are asthenic persons with long spines, exaggerated lumbar lordosis with the spinous processes ap-

proaching one another, and with small lumbosacral angles The second group includes short, obese, hyperasthenic individuals Brailsford believes that those engaged in hard labor show diminished lumbosacral angles These data require careful verification

It has been claimed, in medicolegal cases, that in the absence of any demonstrable cause for back pain, a decreased lumbosacral angle could be assumed to be the etiologic factor It is, therefore, very important to determine whether there be such an entity as an "abnormal lumbosacral angle," and how such an "abnormal angle" is to be recognized

In studying our cases, we found no differences in the values of the lumbosacral angles of the adolescent and the aged and could not find any proof of the existence of an "abnormal lumbosacral angle " We could not determine that any of our cases had sustained any notable trauma to the spine and we must conclude that the stresses of everyday life do not cause material changes in the lumbosacral angle

4. Clinical diagnosis

One might be able to recognize an "abnormal lumbosacral angle," if fortunate enough to have available, for comparison, a radiograph made at some previous time In the absence of such evidence, one may not say that there exists an abnormal lumbosacral angle The values which Robinson and Grimm considered to be abnormal (less than 145 degrees), and to be a factor in the production of back pain are according to table 9 too near the average values to be considered abnormal

To solve the problem, much more investigation similar to that of Hellner is needed His studies, carried out on a rather small scale, confirmed our own findings The studies of Muller and Zwerg of the lumbosacral angulation with the subject in the upright position should be continued on a larger scale

5. Variations in the lumbosacral angle in spondylolisthesis (*sacrum acutum*)

Since variations in the lumbosacral angle were common in spondylolisthesis, we studied lateral radiographs of the lumbosacral spine in 17 cases of spondylolisthesis and carried out careful measurements The average of the measurements of the lumbosacral angle was 152 2 degrees with upper and lower limits of 166 and 128 degrees The angle of the promontory was found to have an average value of 140 1 degrees, with limits of 165 and 116 degrees Hence, the average values were seen to be 10 degrees greater than those found in adults in general (see table 9) This offers rather definite evidence that "tilting of the pelvis" occurs in true spondylisthesis

Whitman describes a syndrome which he calls "prespondylolisthesis" and which is associated with a diminished lumbosacral angle Wegener and Wynan are of the opinion that persons with marked wedging of L 5 and a small lumbosacral angle (90 degrees) are predisposed to spondylolisthesis There is no doubt that marked decrease in the lumbosacral angle may occur, and Scherb calls such cases "acuminate sacrum" (sacrum acutum) Since we were unable to find any etiologic relation between the lumbosacral angle and vertebral slipping, we do not believe the use of the term "prespondylolisthesis" to be justified, and it seems only to add to the confusion already existing

VII. Pathologic Changes in the Mobility of the Spine

In the paragraph on the spine as a whole (p 19), we discussed the goniometric data on the normal movements of the various sections of the spine and pointed out that the amplitude of motion in the living is less than that measured on a cadaver The determination of the amplitude of motion of a spine which exhibits pathologic changes is even more difficult Nevertheless, the importance of such studies is equal to that of the study of the various deformities, and one must consider the amplitude of motion, including rotation, which may be noted in flexion, extension, right and left bending, etc Not infrequently, the muscle spasm and guarding which attends pain prohibits any very precise study of spinal mobility, and examination under general anesthesia may be essential

A. Excessive mobility

As a rule the structure of the ribs and the soft tissues of the thoracic cage prevents clinical recognition of excessive mobility, but since it has an actual anatomic basis, it may produce pain and muscle spasm which may counteract the abnormal mobility and which may even result in a paradoxic rigidity of the spine In spines removed at autopsy, however, it was frequently possible to demonstrate increased mobility Almost all fresh nonimpacted vertebral fractures show increased mobility in the region of the fracture, and we were able to demonstrate abnormal mobility in regions with involvement by infectious spondylitis and extensive destruction (*e g* , tuberculosis), and in spines with osteolytic metastases In a large series of severe vertebral fractures, Magnus was unable to demonstrate excessive mobility in the living subjects

It is not known whether the extraordinary mobility of the spines of contortionists is due to the presence of discs of unusual forms, or reflects the presence of variations in the shape of the vertebral articular processes or to modifications in kinesthetic sense Autopsy examination of such an individual might determine whether the unusual mobility is permitted by modifications in the disc-ligament apparatus or to actual morphologic changes resulting from continued forced motions and, perhaps, the extent to which the suppression of homologous stimuli may be a factor

In an anatomic specimen abnormal mobility in any direction is made possible by disc chondrosis (fragmentation, fissuring of the disc) or by destruction of the disc by an infectious process With an accompanying relaxation of the other components of the motor segment (*e g* , the articular processes), the abnormal mobility becomes even more marked (chapter I H) In the living, the execution of these movements is inhibited by pain and instead of loosening there may be gradually developing fibrotic and osseous changes leading to ankylosis The history and radiographic findings may permit recognition of "loosening of a motor segment" and the institution of appropriate treatment

B. The ankyloses

1. Synostosis

The not infrequently encountered spinal rigidity which results from extrinsic factors (muscular contractures, myositis ossificans and rib synostosis) is beyond the scope of this monograph and will not be discussed

The most frequent cause of ankylosis is new-bone formation which, in turn, may follow numerous pathologic changes Among the more common of these is osteophyte formation in spondylosis deformans, with bridging of one or several disc spaces As we have described previously, the osteophytes represent a response to the stimulus of motion and appear on the margins of the vertebral bodies With the establishment of ankylosis, architectural rearrangement of the new bone (the

osteophytes) occur, and the bony bridges become quite smooth, assuming an appearance which Rokitansky and Wenzel have described as "glazed frosting" (chapter V F) The morphology of the osteophytes is determined by various factors and by static and dynamic disorders which, in turn, are determined by the nature and the severity of the process

Localized ankylosis may result from numerous causes Osteophyte formation may follow an infectious process but does not necessarily result in ankylosis Following destruction of a disc (by infection, trauma or degeneration) bone tissue of the vertebral body may infiltrate the disc space with formation of a complete synostosis of two vertebral bodies (figs 227, 317, 334, 335, 349 and 350) The bone trabeculae are easily recognized within the intervertebral space and are not likely to be mistaken for osteophytes

In its advanced stage, senile kyphosis is characterized by ankylosis of the kyphotic thoracic spine, the result of the bone proliferation which occurs in the anterior portions of the discs (chapter VI A 3) The bridging of the disc space by the growing bone trabeculae is easily recognizable radiographically (figs 392 and 393)

Ossification of the interspinous and yellow ligaments may result in ankylosis, particularly in the thoracic region (fig 221) It is usually incomplete, and the degree of limitation of motion is variable Isolated ossification of ligaments is not the rule and occurs mainly in connection with senile kyphosis and spondylosis deformans It appears that the ossification process is initiated by some degree of rigidity of a motor segment induced by some other process Ossification of the ligaments in ankylosing spondylarthritis will be discussed in the following section (B 2)

Degenerative changes of the articular processes may produce a more or less complete ankylosis (fig 220) Like spondylosis deformans, arthrosis deformans of the small joints is a manifestation of the wear and tear process, but it is curious that these two diseases almost never exhibit, simultaneously, the same severity of symptoms Moreover, arthrosis deformans and spondylosis deformans are quite variable as to location and development, although the more mobile regions (*i e*, the cervical and lumbar regions) are the most commonly involved (see p 123) The whole problem of arthrosis deformans is still unsolved, and it remains to be seen to what extent it is dependent on the stresses of everyday life and repeated small traumas, and when and to what extent it causes pain Pseudospondylolisthesis, which is closely related to arthrosis deformans of the small joints, will be discussed in chapter VIII B

The synostosis of congenital block vertebra has been discussed on page 26 (figs 44—46) and the relation of block vertebra to other anomalies was described on page 57

2. Ankylosing spondylarthritis (Marie-Strumpell's disease)

Ankylosing spondylarthritis (known in the French literature as "Spondylose rhizomélique") has been considered as a disease of the spine, with two types of the disease distinguished (1) Bechterew's disease (confined entirely to the spine) and (2) Marie-Strümpell's disease (with involvement of the sacroiliac synchondroses and the symphysis pubis) Since Bechterew's description does not seem to be applicable to ankylosing spondylarthritis which, according to Bruckley, was described by Connor in 1700, the name "Bechterew's disease" should be avoided (Oehlecker, Ott, Pitzen) In the light of our present knowledge, ankylosing spondylarthritis is to be considered as rheumatoid arthritis of the small vertebral joints, as Klinge has shown and as agreed on by numerous writers Such etiologic factors as cold, focal infection, gonorrhea, etc, have long been suspected (Benassi and Rizatti, Buckley, Ehrlich, Federschmidt, A Fischer, Höhne, Koch, Krahnstöver, Krebs, Kroner, Liakhovitzki Nachlas, Schanke and others) Höhne, Tempelaar, Teschendorf, and E Volhard find that iritis is frequently an associated finding In the early stages, there is elevation of the sedimentation rate (Crosetti, A Fischer, Güntze, Höhne) Various writers believe that the parathyroid hormone has an etiologic role in this disease and that its suppression by ablation or by vessel ligation (Lériche) may be followed by disappearance or, at least, amelioration of the symptoms and the metabolism of calcium and glucose (Appel, Chiasserini, Crosetti, Francon and Chpail, Hoffmeister, Jasienski Mallet-Guy) Lead poisoning (Werthemann and Rintelen), trauma, and upper respiratory

tract infections (Ehrlich, E Frankel, Geilinger, Heiligenthal, Heinemann-Grüder) are among the suggested etiologic factors and Coste has assumed a virus (Chlamidozoon oculo-genitale) as a possible cause Hereditary factors have been mentioned by various writers (Anschütz, Böni, Ehrlich, Fischer and Vontz, Geilinger, Jacobs and Rose, Magnus-Levy, Weil, and others), and it seems that the disease is more common in males (Benassi, Bizzatti, Kroner, W Müller, E Volhard et al)

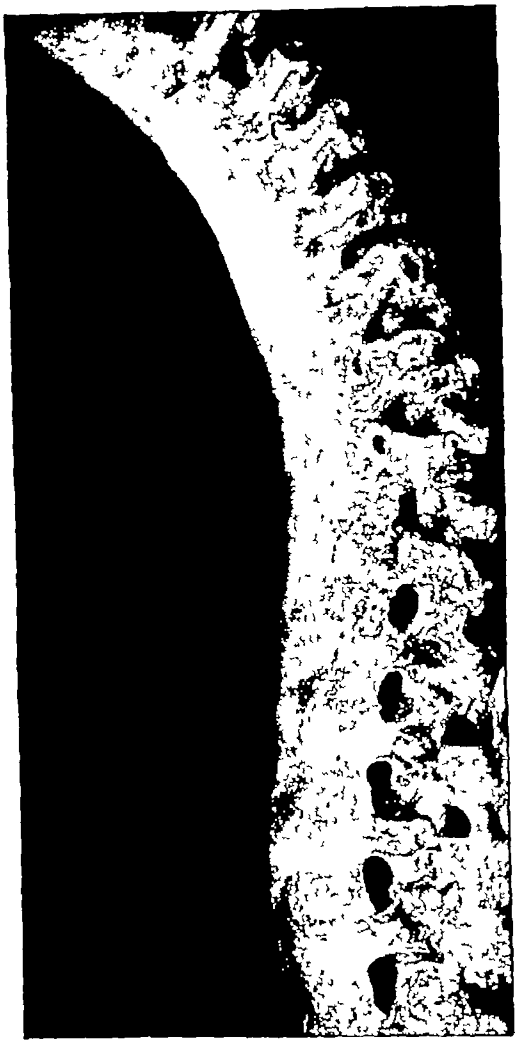


Fig 405 (left) Photograph of the macerated spine Man, age 60 Ankylosing spondylarthritis Ossification of the anterior longitudinal ligament and of all the small vertebral joints No osteophyte formation

Fig 406 (right) Photograph of a sagittal section of the specimen shown in fig 405 Marked ossification of the entire anterior longitudinal ligament without osteophytes Marked osteoporosis Ossification of the other ligaments Ossification of the discs

E Volhard attributes special significance to infection of the prostate and says, "Ankylosing spondylarthritis represents a chronic infection, of prostatic origin, involving the connective tissue of the pelvis and the spine, and continuously ascending through the lymphatic channels " In the great majority of cases he found a history of gonorrhea Prostatic infections of other origins (typhoid, dysentery, etc) may also be etiologic factors His thesis, however, has been disputed by various authors, notably Domdey, Simpson and Stevenson Romanus is in agreement with Volhard and concedes that the origin of the disease is to be found in the pelvis and is willing to include the sigmoid colon, rectum and the urogenital tract He proposes a new name, "pelvospondylitis ossificans" and Ravelli accepts this, since he found similar bone changes in osteitis pubis which, as Wachs demonstrated, occurs in pelvic inflammatory disease Vaubel, however, rejects gonorrhea as an etiologic factor

and, after giving a detailed description of a case of scleroderma, considers the disease as a form of "sclerodystrophy" Steffens considers ankylosing spondylarthritis to be an endocrine disorder, rather than an inflammatory disease, and Pitzen is inclined to favor constitutional and hormonal disorders

Based on his anatomicopathologic studies, Aufdermauer concluded that ankylosing spondylarthritis is a disease of inflammatory origin belonging to the group of the arthritides but, as Böni and others have shown, he regards the actual cause as unknown Böni believes that there is an hereditary and constitutional predisposition to the disease and that stress (including the exhaustion-syndrome, infections, nutritional deficiencies etc) may act as the "trigger mechanism"

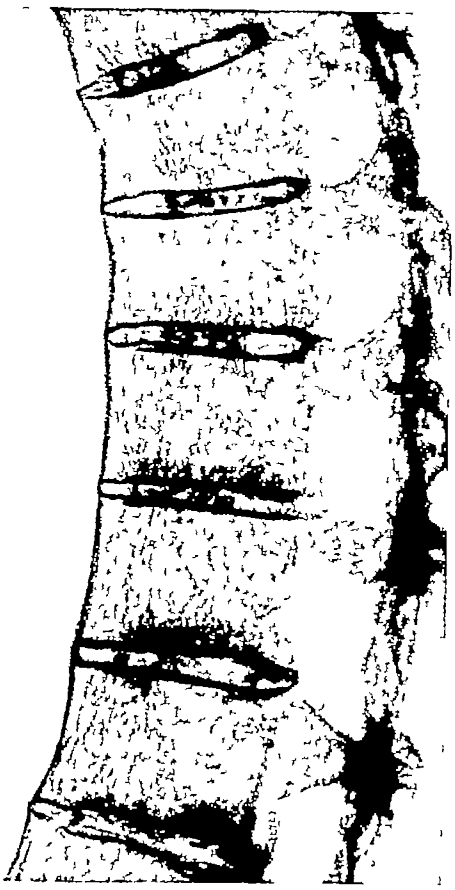


Fig 407 (left) Lateral radiograph of a sagittal section of the spine Man, age 71 Ankylosing spondylarthritis with complete ossification of all of the small vertebral joints and of the anterior longitudinal ligament Narrowed intervertebral spaces with osseous foci in the discs

Fig 408 (right) Radiograph of the lumbar spine Man, age 50 Bamboo spine of advanced ankylosing spondylarthritis Note the ossification of the ligaments of the spinous processes and the obliteration of the sacroiliac joints

For the anatomist, an advanced case of ankylosing spondylarthritis demonstrates a completely rigid spine in which ossification of the entire anterior longitudinal ligament and nearly all of the other vertebral ligaments (the interspinous ligaments, the yellow ligaments, etc) has resulted in the production of a solid column of bone (figs 405 and 406) The solid fusion and the obliteration of the articular spaces of the small joints may be recognized radiographically and the intervertebral discs, originally well-preserved, are replaced by cancellous bone The marked osteoporosis of the vertebral bodies, somewhat overshadowed by the sheath-like thickened and ossified longitudinal ligaments (figs 405—407), constitute the picture of a typical "bamboo spine" (fig 408)

Histologic studies indicate that the initial site of the disease is the small vertebral joints, and the lesions are comparable to those of the various evolutionary phases of chronic infectious arthritis (Guntz, Klinge, M Lange, Siven) The articular interspaces are filled with fibrous tissue (probably of synovial origin), infiltrating lymphocytes and remnants of articular cartilage Kienböck's opinion that ankylosing spondylarthritis represents a special form of serous exudative tuberculosis seems to be without foundation The development of the ankylosis is an insidious process (Aufdermauer, Wurm) It is of interest to note that Güntz was unable to discover any histologic evidence of inflammatory changes in the ossified longitudinal ligament Whether the extensive ossification of the ligaments is due to the immobilization resulting from synostosis of the small joints (fig 408) or reflects an inflammatory process of the ligaments is still to be decided The costovertebral joints

(fig 367) participate in the ossification process, leading to gradual immobilization of the thorax and respiratory embarassment The early ankylosis of the sacroiliac synchondroses has been discussed on page 129

Romanus thinks that the disease is preceded by a hereto unnoticed "destructive phase," in which the external surfaces of the vertebral bodies, the disc, and the articular processes are eroded by a radiographically demonstrable inflammatory process This process is followed by calcification and ossification, and he observed this sequence of events in the sacroiliac synchondroses and the symphysis pubis Aufdermauer has presented a detailed description of the anatomic and pathologic findings Wurm observed lymphocytic infiltration of the tissue between the vertebral bodies and the posterior longitudinal ligament and believes that a chronic inflammatory process of synovia and the loose parosteal connective tissue induces a disturbance of the autonomic system which may lead to nutritional disorders and to subsequent ossification

It is only since the advent of the general use of radiography that ankylosing spondylarthritis has been recognized in the living, but in recent years numerous cases have been reported (Ehrlich, Fischer and Vontz et al) We found only 6 or 8 cases of this disease among the 10,000 spines in the Dresden Institute, but possibly some cases with early changes escaped detection After study of a large amount of radiographic material, Bachmann estimated a frequency of occurrence at 2 per cent Krebs finds that spondylosis deformans occurs ten times more frequently than does ankylosing spondylarthritis

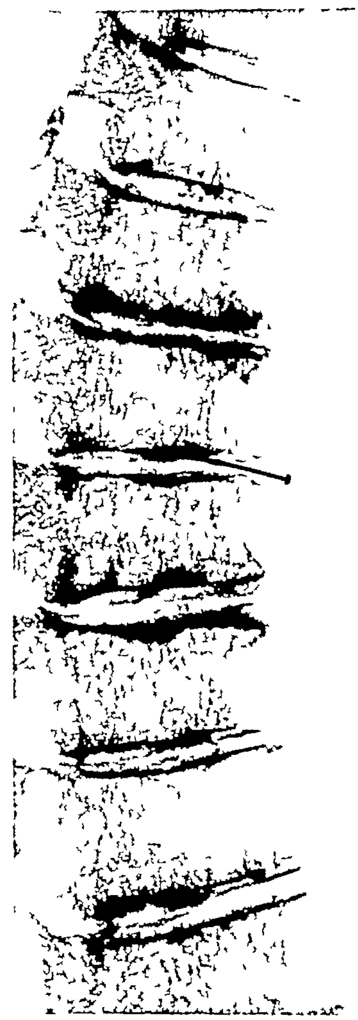


Fig 409 Lateral radiograph of a sagittal section of the thoracic spine Man, age 76 Pin lodged in the T 6 — T 7 disc Narrow intervertebral spaces with irregular eburnation of the adjacent vertebral plates Disc spaces filled with dense sclerotic connective tissue resulting in "fibrous" ankylosis of the spine

It must be remembered that in the differentiation between spondylosis deformans and ankylosing spondylarthritis, there are numerous other disease entities to be considered (Bachmann, Ehrlich, Engelen, Pflucker et al) Severe pain accompanying ankylosing spondylarthritis suggests a series of extrinsic processes, including occipital neuralgia, angina pectoris, pleural and pulmonary diseases, tabetic crisis and intra-abdominal diseases (Schereschewsky)

Kienböck and Meisels have described a bone disease resembling ankylosing spondylarthritis and have called it "hypertrophic ossidesmosis " It is characterized by a radiographically demonstrable generalized osteosclerosis with arrest of bone growth, and the vertebral rims remain separated from the vertebral bodies for a long time Since no anatomic studies of this syndrome are available, its pathogenesis and its classification remain uncertain

Bibliography dealing with the history and therapeutic measures of ankylosing spondylarthritis Aalvik, Arnold, Bemann, Cervenansky, Dressler, Edström, Eltze, Engelen, Fritz, Gold, de Gaetano, Grauer, Hart, Iselin, Krebs, Lux, Murno, Neergard, Neumann, Raszeja, Salvatori, Seppä, Slauck, Steffens, Stiasny, Teodori, Wolff

3. Fibrous ankylosis

Ankylosis of the spine is not always due to bone fusion, and rigidity of large portions of the spine may be of other origin This was first recognized by Schmorl, and Güntz (of Schmorl's Institute) published a study of this problem The process appears to result from fibrotic changes in the inter-

There is an increasing acceptance of the thesis that such "lockings" do occur in the vertebral column, and that they may sometimes be mobilized by manipulation or may undergo spontaneous loosening (chapters III H 4, IV B 4, p 157) Such maneuvers are not of recent origin, but have been known for centuries (Avicenna, Biedermann, A Cramer, Derbolowsky, Gutmann, Gutzeit, Nägeli, von Roques, Sell, Sollmann, Zukschwerdt)

A. Spondylolisthesis due to acquired changes in the pars interarticularis

In addition to "true spondylolisthesis," which occurs only with a congenital cleavage of the pars interarticularis, one may observe anterior displacement of a vertebral body and the anterior portion of its arch, resulting from other changes in the arch, as bilateral fractures of the pars interarticularis

Fig 412 (left) Photograph of a sagittal section of the lumbosacral spine Woman, age 72 This specimen shows findings comparable to those in figure 411 Protrusion of an osteophyte into the intervertebral foramen

Fig 413 (right) Lateral radiograph of a sagittal section of the lumbosacral spine Woman, age 58 Pseudospondylolisthesis of L 4

and subsequent degeneration of the disc (Böhler, George and Leonhard, Hellner, Hermodsson, Holfelder, Lutz, Meyer-Burgdorff, Mjakotnich, Perlman and Hawes, Reissner, Ryzov, Schanz, Scheid and Malluche) Such cases constitute very difficult medicolegal problems, and frequently it is impossible to decide whether the changes are partly, entirely or, even at all, of traumatic origin (Bachmann, Brocher, Francillon) Hadley's opinion that fusiform thickening of the pars interarticularis indicates a healed fracture is questionable Rather rarely, infection or neoplastic involvement of the arch may lead to anterior vertebral slipping (Abraham, Follmer, Reissner, Sisefsky) Thus far, the diagnosis in such cases rests on radiographic evidence, and there are no anatomic studies to confirm it In chapter II C 3 we have discussed the controversy surrounding cleavage of the pars interarticularis, and the possibility of the existence of "umbauzones"

B. Pseudospondylolisthesis

Junghanns has studied 14 cases of a particular form of anterior vertebral slipping, resembling the initial stage of spondylolisthesis but without cleavage of the pars interarticularis These he called "pseudospondylolisthesis," and a schematic representation of this lesion is presented in figure 410 The pars interarticularis is intact, but the angle formed by the pedicle and the axis of the inferior articular process is considerably greater than that observed in an adjacent vertebra The angle between the pedicle and the superior articular process of L 5 is diminished and the space L 4—L 5 exhibits a more horizontal orientation (see arrows in fig 410) Radiographs and photographs of the anatomic specimen show the changes illustrated in the drawing (figs 412 and 413)

The anatomic specimen of a vertebra involved in pseudospondylolisthesis exhibits certain special features The articular surfaces of the inferior articular processes show the marked osteophytosis of arthrosis deformans and complete destruction of the articular cartilage Similar changes involve the superior articular processes of the vertebra next below The small joints of the neighboring vertebrae do not show such marked degenerative changes, but the disc below the slipped vertebra shows degenerative changes (intervertebral chondrosis) resembling those seen in true spondylolisthesis Osteophyte formation is present on the vertebral margins and all of the components of the corresponding motor segment show radiographically demonstrable characteristic changes

The essential features of pseudospondylolisthesis are slight anterior vertebral slipping, changed orientation of the articular facets and arthrosis deformans of the small joints of the participating vertebrae The disc changes are secondary in nature, but we do not know whether the altered orientation of the articular facets is congenital or secondary to the arthrosis deformans Nor do we know the extent to which the changed orientation of the articular process predisposes to slipping of the vertebra in question (Chiari, Goldthwait et al) On page 41 the cases of pseudospondylolisthesis seen in the Dresden Institute are surveyed in tabular form The ages of the patients varied between 56 and 87 The frequency of occurrence of this disease in females and the involvement of L 4 is quite striking In true spondylolisthesis it is usually L 5 that is involved and there is a less marked differentiation as to sex Bibliography Adkins, de Cuveland and Eufinger, Friedl, Hadley, Hallgrimsson, Jonsson, Macnab, Meyer-Burgdorff, W Müller, Potter and Norcross, Reissner, Rössler, Sonnenschein, Stewart, Vilaseca and Casademont, and others

Fig 414 Photograph of a sagittal section of the lumbar spine Woman, age 75 L 1 is displaced slightly posteriorly Narrowing of the disc space L 1—L 2 with marked fragmentation of the disc tissue, with prolapse into the intervertebral foramen

C. Retrolisthesis*

Posterior vertebral displacement is sometimes observed when lateral radiographs or sagittal sections of the spine are studied The "shelf" appearance is easily recognized at the posterior margins of the vertebrae, since osteophytosis does not occur there In the collection of spines in Schmorl's Institute, retrolisthesis was seen to involve, usually, the upper lumbar spine at the level of L 2 in

* A term used to indicate the vertebral displacement frequently described as "reverse spondylolisthesis" (ed)

8 cases and at the level of L 1 in 1 case (Junghanns) The upper spinal segment is displaced posteriorly (in relation to the vertebra below) and the disc below shows degenerative changes with narrowing of the disc space, as may be seen in spondylolisthesis, pseudospondylolisthesis and osteochondrosis (chapter IV C 2) Eburnation of bone occurs at the level of the displacement and there is always a moderate degree of osteophytosis (figs 414 and 415)

Fig 415 (left) Lateral radiograph of a sagittal section of the lumbar spine Man, age 67 Marked narrowing of the disc space L 2—L 3 with eburnation of the adjacent vertebral plates Displacement of L 2 posteriorly resulting in a narrowing of the intervertebral foramen Misalignment of the small vertebral joints (arrows)

Fig 416 (right) Lateral radiograph of a sagittal section of a portion of the lumbar spine Woman, age 72 Slight posterior displacement of L 2 Narrowing of disc space L 2 — L 3 with prolapse of the disc into the body of L 3 (possibly post-traumatic) Protrusion of osteophytes into the intervertebral foramen L 2 — L 3

Cleavage, or other architectural change in the vertebral arch, is not the cause of retrolisthesis, which, rather, is produced by alterations in the relationship of the articular processes with "settling" (or downward motion) of the inferior articular processes on the superior processes of the vertebra below (arrow in fig 415) This, and straightening of the spine above the displacement, are characteristic changes in the appearance of the motor segment (Güntz) These changes, and the associated narrowing of the disc space appear to be responsible for the retrolisthesis This narrowing is especially marked when it is the result of the prolapse of disc tissue into the vertebral body (fig 416) and disc prolapse, osteochondrosis, etc , are important factors in the production of retrolisthesis in the upper lumbar spine It is not known whether the disc changes are primarily responsible for the displacement, or whether arthrosis and loosening of the small joints produce the disc changes which, in turn, lead to the retrolisthesis If the latter is the case then the small joints must have a primary responsibility for the displacement

Clinical study indicates that retrolisthesis may affect several superimposed vertebrae and may give rise to numerous symptoms (fig 417) The careful study of radiographs made in the lateral position will result in more frequent recognition of this form of vertebral displacement Muscle

spasm usually immobilizes the affected segment, particularly in forward and backward motion of the spine Lateral motion is not usually limited in any great degree Hyperextension, which is very painful, accentuates the "stair-case" appearance seen in a lateral projection The rigidity

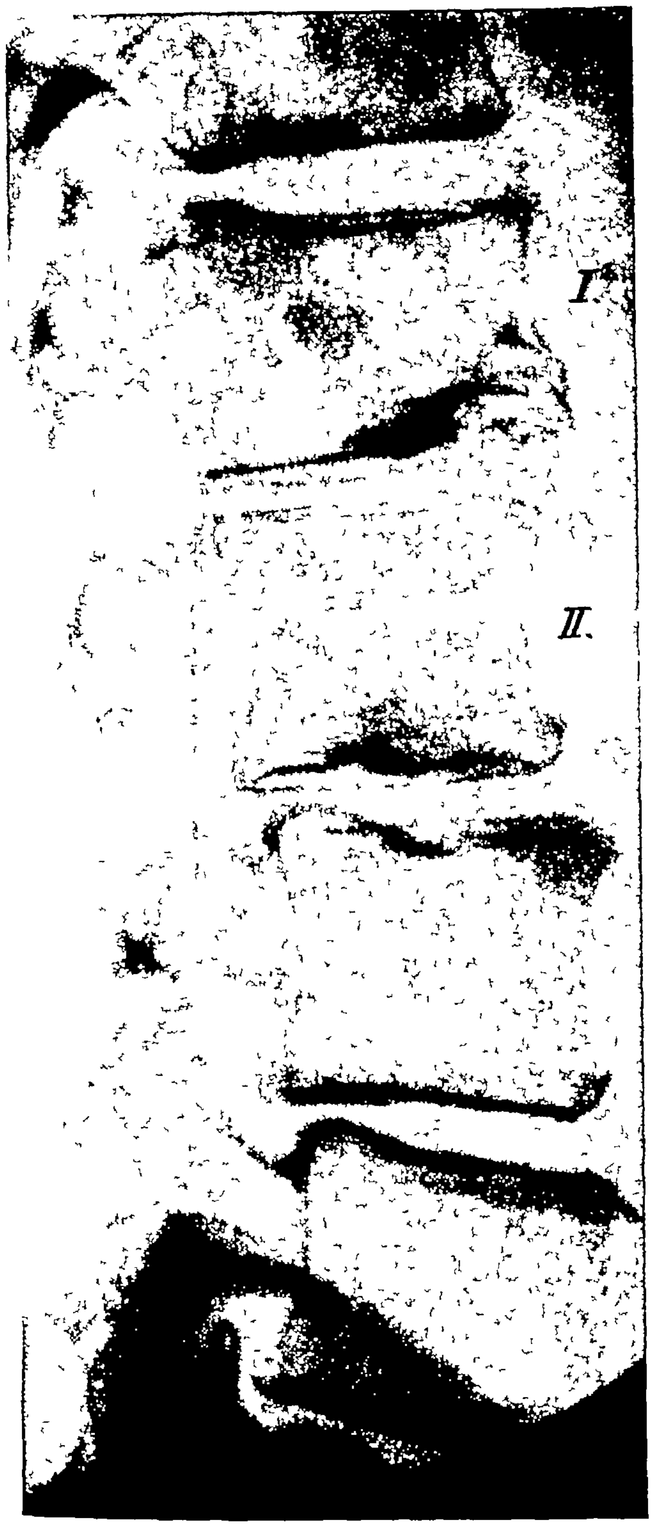


Fig 418 Photograph of the macerated spine of a 53 year old man Hemisacralization on the left Lumbar scoliosis with the convexity to the left Lateral displacement and rotation of L 3

Fig 417 (left) Lateral radiograph of the lumbar spine Man, age 51 Irregularity of the inferior plate of L 1 (I), marginal fracture Narrowing of several disc spaces, Schmorl's nodes Slight posterior displacement of several vertebrae Gapping of the small vertebral joints

(due to pain) of the spine of the patient shown in figure 417 had been considered to represent ankylosing spondylarthritis (chapter VII B 2), although careful study of the lateral radiograph would have enabled the avoidance of this error The confusion of retrolisthesis with fibrous ankylosis may also be avoided by careful clinical and radiographic study (chapter VII B 3)

Hagelstamm considers retrolisthesis to be among the early signs of tuberculous spondylitis and thinks that it precedes the destructive changes in the vertebral body Brocher describes posterior vertebral displacement following rupture of the ligaments and has demonstrated it in cadavers

Hackethal found, in a series of 137 vertebral fractures, that 70 per cent of the fractured vertebrae were displaced backward and that 20 per cent of the cases seen exhibited posterior displacement of the vertebra below the level of the fracture

Bibliography Brocher, Diez, Gillespie, Johnson, Lawson, Mosenthal, W Müller, Roaf, de Sèze and Durieux, Smith, de Veer, Vilaseca, Vogt, Weindruch and Koretzky, Zaremba

D. Lateral vertebral displacement (rotatory slipping)

Lateral vertebral slipping is of rare occurrence Junghanns observed it in cases of tabes dorsalis, but the actual mechanism appears to be extensive destructive changes in the vertebral bodies and

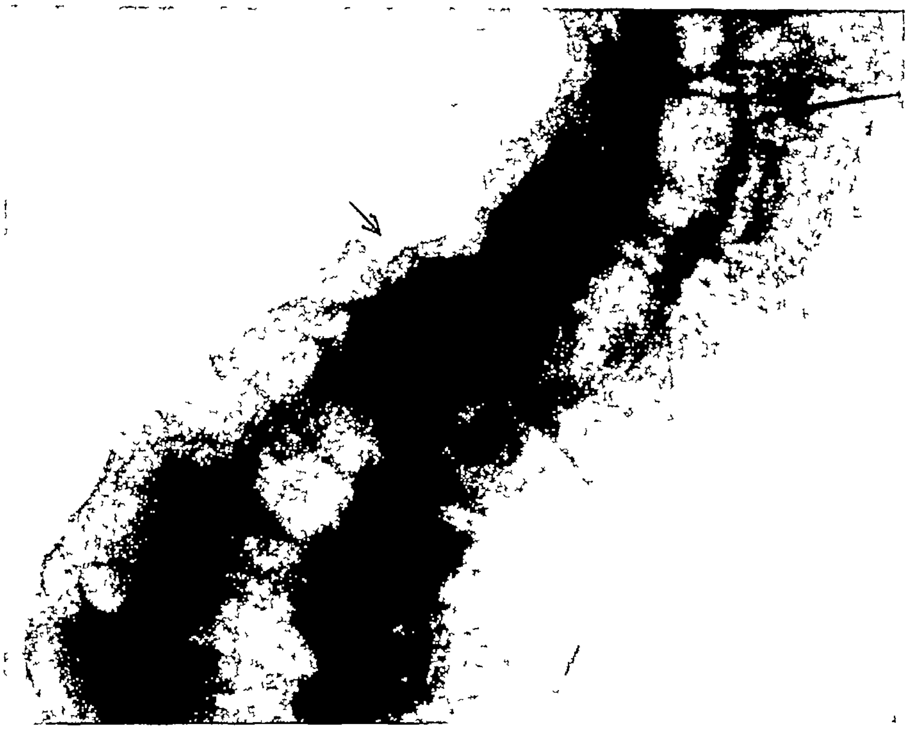


Fig 419 Radiograph of the specimen shown in figure 418

the discs (Breitländer) Traumatic lateral displacement of the vertebrae was discussed on page 92 (fig 166) In a series of 1600 radiographs, Horsch found only 11 instances of lateral vertebral displacement Most of these were in the cervical spine although a few occurred in the lumbosacral region Lateral displacement may occur as the result of a gradual process of disc destruction, or it may occur as a sudden and painful event Lateral displacement of a vertebra in lumbar scoliosis has been described by Junghanns and seems to be of particular significance (figs 418 and 419) Disc destruction and narrowing of the disc space is always seen, and osteophytosis is common W Müller finds that lateral displacement is accompanied, invariably, by vertebral rotation Associated symptoms are usually present (Hohmann, Imhäuser, Lindemann, W Müller, Nitsche) Lateral displacement with vertebral rotation is a late complication of juvenile kyphosis but neither Reinhardt nor Lindemann find rotatory displacement in congenital scoliosis These displacements should not be described as spondylolisthesis, as is so frequently done in the literature (Fenkner et al)

IX. The Lumbosacral Region

The lumbosacral region is a complex region, the ontogenetic development of which has not yet ceased (Liek), in which radiologic study is becoming increasingly important for the clinician, as new and improved technics are developed (Dittmar, Harttung, Meyer-Burgdorff, Stuck, Warner et al) We must, first of all, find a firm anatomicopathologic basis for the syndrome of low-back pain and separate it from the vague and confused group of "lumbosacral disorders" (Bársony, Curschmann, Goljanitzki, Lowman, Nordmann, v d Osten-Sacken, Piccinino and others) The complex anatomy of this region, the radiographic superimposition of the shadows of the various structures and the numerous variations in the orientation of the articular processes combine to produce the difficulties which attend the study of the lumbosacral area (Brailsford, Meyer-Burgdorff, Schede) Bohart compares the spine with the individual features which distinguish a given face, and the comparison seems especially apt when the lumbosacral region is that part of the spine which is being studied O'Reilly found very marked changes in the lumbosacral spines of 50 per cent of patients examined and Pugh thinks that the figure should be greater (85 per cent) Pugh adds, however, that only a fraction of these patients have complaints attributable to the lumbosacral region In Rich's series, only 30 per cent of patients with low-back pain showed any significant changes at the lumbosacral level Heise reviewed 1,050 radiographs of the lumbosacral spine and found variation from the normal in more than 60 per cent of them According to Hellstein 8 8 per cent of patients seen in the Russian polyclinics complained of low-back pain

If we remember that the lumbosacral region is the area of transition of the mobile spine into the rigid sacrum, firmly fixed in the pelvic ring, and that the sacrum is the pivot for all of the important axial motions of the body while the last presacral disc must sustain the stresses imposed by the entire spine, the early appearance of wear and tear will be less astonishing Since this area is also the site of numerous congenital anomalies, the prevalence of painful disorders is quite understandable

In preceding chapters, we have discussed the various anatomic and pathologic changes which may be responsible for low-back pain Among these were Schmorl's nodes, variations in the lumbosacral angle, transitional vertebrae, cleft arches and many others Back pain may also be produced by lesions in the upper regions of the spine (spinal deformities, vertebral fractures) which disturb the statics of the vertebral column The extent to which such changes as disc degeneration, narrowing of the disc spaces, etc , involve the lumbosacral region (as compared to other spinal areas) has been discussed in various sections of this monograph (Junghanns) A study of low-back pain considered as an entity, and with consideration of all of its aspects, would be very useful to the clinician, and attempts at such comprehensive studies may be found in the literature (Brailsford, Brocher, W C Campbell, Curschmann, Debrunner, Goldthwait, zur Verth, Wilhelm, Willis et al)

The lumbosacral region is of considerable importance in obstetrics (Martius) since, in addition to possible osseous changes, one must consider the problem of the relaxation induced by hormones (*e g* , during pregnancy and the menstrual cycle) and the occurrence of pelvic disease (Albrecht, Becker, Saxl et al) The urogenital tract (including the prostate), the intestinal tract, the musculature of the back and the abdomen, and the vessels and nerves of the pelvis may be of importance in the causation of low-back pain or "sciatica," and must be considered in differential diagnosis Disturbed statics, produced by flat feet or other deformities of the lower extremities, may be of etiologic significance in the production of this syndrome

Since low-back pain is of great importance in industrial, social and forensic medicine, we have selected a few publications from the large bibliography which deals with this subject Albrecht, Andrew, Baikow

and Bassow, Brofeld, Chalmers, Clement, Cochrane, Le Cocq, Duncan, Engelien, Erdmann, Ph Erlacher, R Erlacher, Ghormley, Glorieux, Graff, Hauser, Hobart, Hohmann, Karfiol, Kirchhoff, Kühn, Lasher, Magnuson, Michotte with Simonart and Danaux, Mitchell, Mock, Nowazilow and Filipow, Pines, Putti, Rapaport, Reinberg and Zatkin, Richard and Delhave and Calvet, Raney, Sabater, Schlegel, Schober, Sladky, Taiclin and Rudenko, Thomsen, Tippet, Watermann, Weil

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